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RAILWAY COLOUR LIGHT SIGNAL:
PHASE II - PROTOTYPE DEVELOPMENT

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FINAL REPORT

RAILWAY COLOUR LIGHT SIGNAL: PHASE II - PROTOTYPE DEVELOPMENT

Prepared For:

TRANSPORTATION DEVELOPMENT CENTRE
Montreal, Quebec

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SEPTEMBER, 1985

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DISCLAIMER

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transport Development Centre or Transport Canada.

PROJECT TEAM

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17. Abstract

This report describes the second phase of a research project to replace conventional lamps with solid-state light-emitting-diodes (LEDs) in railway colour light signals. Phase II focussed upon the design and manufacture of prototypes suitable for field viewing. Two concepts were developed - a retrofit package for existing signals, and an optimized array taking full advantage of unique features of LEDs.

LED signals replace all moving parts and filters with an array of red, yellow and green chips wired in banks. Colour is selected by switching one bank on. Conversion of electrical energy to light is direct and efficient, reliability is high and lamp replacement is eliminated.

Minimum requirements of 400 m range were exceeded; however, LED brightness does not yet permit the full 1600 m equivalent of a conventional signal in yellow or green. Also, green LEDs do not yet meet international colour standards used by the railways, although visually the result was satisfactory.

Requirements for retrofit logic conversions were investigated but not built. Also, breadboard optics of an alternative, multi-facetted lense signal were fabricated, achieving beam angle, longer range and lower power consumption.

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17. Résumé

Ce rapport décrit les travaux de la seconde phase du programme de recherche visant le remplacement des feux de signalisation ferroviaire classiques par d'autres à doides électroluminescentes (DEL) à semi-conducteurs. Ces travaux ont porté essentiellement sur l'étude et la réalisation de prototypes expérimentaux. Deux approches ont été suivies: un ensemble électronique s'emboîtant dans les matériels existants et un jeu de feux électroniques tirant parti des caractéristiques particulières des DEL.

Toutes les parties mécaniques ainsi que les filtres du feu classique sont remplacés par des moyens électroniques, les couleurs jaune, rouge et verte voulues étant produites par les DEL. La conversion de l'énergie électrique en lumière se fait de manière plus directe, efficace et fiable qu'avec les lampes à tungstène.

La luminance des DEL n'a pas encore une portée équivalente a celle (1600 m) des feux jaune et vert classiques, bien que la portée minimum de 400 m ait été dépassée. En outre, la couleur verte des DEL ne respecte pas tout à fait la norme internationale en signalisation ferroviaire, même si le résultat obtenu a été jugé satisfaisant.

La recherche a porté sur les moyens de convertir les logiques de commande, mais sans aller jusqu'a l'étape de réalisation. Par ailleurs, la maquette expérimentale d'un système optique comportant une glace plane à facettes multiples a été réalisée, ayant la directivité voulue, une portée plus grande et une consommation plus viable.

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TYPE 1 - LED ARRAY SEARCHLIGHT

1.0 INTRODUCTION

This report details the work performed and the results achieved in the period August 1984 - August 1985, concerning the prototype development of solid-state, three-colour searchlight signals for railway use. The work is in direct consequence of a previous study done for TDC over the period September 1983 - April 1984, entitled "Railway Colour Light Signal: Preliminary Design" (Transport Canada Report No. TP5452E) in which the feasibility and basic configurations were established. These results were sufficiently encouraging to warrant further expenditures, with the objective of manufacturing prototypes suitable for comparison tests in a railway environment.

The results of the current work have been that a number of prototypes have been manufactured, and testing at Davis indicates that most meet or exceed the minimum requirements specified in the project work statement. As development proceeded, however, more emphasis came to be placed on experimentation and rather less on production of quantities of prototypes than had been anticipated. This process was highly interactive with the project Steering Committee, who constantly encouraged and guided the project team.

The remainder of this report details the development process, the resultant hardware and measured performance. Partial records of major meetings and formal tests are provided as appendices.

2.0 SCOPE AND OBJECTIVES

2.1 SCOPE OF WORK

The project scope encompassed an analysis of the previous work, the choice of a limited set of designs to prototype, the provision of working prototypes, and the design of electronic interfaces.

2.2 OBJECTIVES

It was desired to provide prototypes of at least two different types that would be suitable for field testing by CN Rail under controlled conditions. The primary specification was a visibility range of at least 400 m (equivalent to 10 seconds at 145 kilometers per hour) with as good colour rendition as possible, given the limited choice of LED chromaticities.

3.0 PROJECT CHRONOLOGY

Because the Steering Committee was quite active in modifying the project plan as it proceeded, in order to maximize the development, many activities overlapped and interacted. These were controlled and recorded through detailed technical notes which form the bulk of the Steering Committee minutes. Exerpts from the Steering Committee minutes and correspondence relevant to them are appended (Appendix C), and the major points summarized below.

Date	Item	Summary
Nov. 8/84	1st committee	- decision analysis begun (prototype selection) - early test of type I range requested - discussions of external involvement
Dec. 20/84	letter to TDC	- results of range tests - possibility of external provision of interface electronics design - next type I prototype under way
Jan. 10/85	2nd committee	- CN to provide interface expertise - immediate thrust on type I - range tests with committee (prototype #1) - decision analysis draft distributed for future review
Jan. 23/85	letter to Davis	- comments from committee on decision analysis - lowering priority on interface as a result of CN/Davis meeting

Date	Item	Summary (continued)
March 7/85	3rd committee	- prototype #2 observed, 800 m. range met
March 14/85	letter to Davis	- minutes of further committee discussion March 7/85 - suggestions from committee for prototype #3 - request for additional experimentation with optical configurations - final 3 prototypes to be deferred pending experiments
April 23/85	4th committee	- report of further range tests, prototype #2 - phantom tests - prototype #3 tests - request for nightime colour test - decision to build type II
May 2/85	Davis note	- results of nightime colour test
May 27/85	5th committee	- reports on experiments: range, optics, colour - definition of further deliverables

From May 27th until the date of this report, the final two type I prototypes and the type II breadboard were designed and in fabrication, in anticipation of the final Steering Committee meeting in August.

4.0 TYPE I PROTOTYPE

The type I concept involves the use of a tightly grouped array of Light Emitting Diodes (LEDs) and a supplementary lense, within an existing searchlight signal housing and utilizing the searchlight signal objective (large, outer) lense (see figure 1, taken from figure 23 of TP5452E). Expanding the area of the array sufficiently to pack in enough LEDs, and matching the power of the negative lense to the desired array diameter and optical position, results in significant light being projected. The array is a mixture of 3 colours of LED's, only one colour of which is energized at a time.

Previous experiments established the concept's feasibility at short range, and it was desired to construct a variety of field prototypes and address range and colour performance.

The various LED's evaluated for both type I and type II along with their specifications can be found in Table 1.

4.1 TYPE I MATRIX ANALYSIS

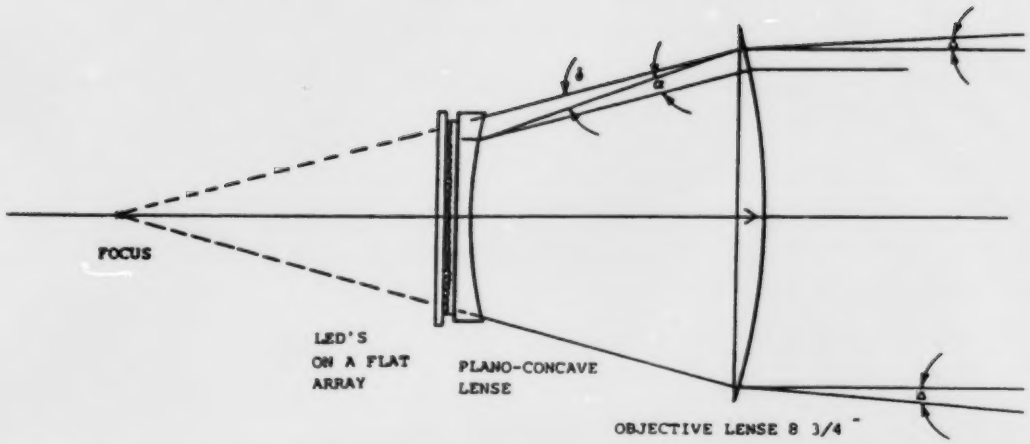
Matrix analysis of the type I array was done early in the project and the results can be found in Appendix A. The summarized recommendations for type I were as follows:

"The prototype will consist of an array of about 200 LED's deflanged and arranged in a hexagonal close-packed uniform pattern of three colours. The LED's will be aligned by their leads in the printed circuit board. The LED's used will be DRI Red, DYI Yellow, and DGI Green (see Table 1). Blue LED's might also be included if they become readily available.

The optics will consist of a plano-concave lense ground from plastic or glass depending on availability. The lense will have a diameter of 88 mm, a focal length of -116 mm and a radius of curvature of 60 mm."

4.2 TYPE I PROTOTYPE FABRICATION

In all, five type I prototypes were fabricated. The first three evolved over the course of the project as more



α IS THE DISPERSION ANGLE OF THE LED'S
Δ IS ONE HALF OF THE COLLIMATED BEAM ANGLE (2°)
f IS THE FOCAL LENGTH OF THE OBJECTIVE LENS

FIGURE 1 TYPE I: OPTICS

TABLE 1

LED'S AND THEIR SPECIFICATIONS

LED	COLOUR	INTENSITY	BEAM ANGLE	DOMINANT WAVELENGTH
DR1	Red	2000 mcd	12°	660 nm
DR2	Red	500 mcd	12°	660 nm
DR3	Red	5000 mcd	12°	660 nm
DR4	Red	3000 mcd	10°	660 nm
DY1	Yellow	140 mcd	24°	583 nm
DY2	Yellow	125 mcd	24°	580 nm
DY3	Yellow	350 mcd	24°	570 nm
DY4	Yellow	500 mcd	12°	unknown
DY5	Yellow	120 mcd	10°	585 nm
DG1	Green	200 mcd	24°	555 nm
DG2	Green	200 mcd	12°	560 nm
DO1	Orange	200 mcd	24°	605 nm

information became known and visual testing proceeded. The final two (shown on page X) are as defined at the 5th Steering Committee meeting, except for the late substitution of better colour yellow LEDs. All the prototypes and their performances are listed in Table 2.

4.2.1 Yellow LEDs

It had been expected that the green LEDs would present the greatest colour difference, since their chromaticity is quite far from the current AAR limits. In fact, the first prototype presented a yellow judged to be less orange than the conventional signal, hence prototype 2 contained a mixture of yellow and amber LEDs for the "yellow" aspect. At close range, the spottiness of this approach was disliked, prompting the committee to direct Davis towards various mixing solutions.

These proved to be very costly in terms of luminance, i.e. a good diffuser also scatters well, whereas the searchlight demands a narrow beam. Prototype 3 was fabricated with DO1 "orange" LEDs, as a shift towards a yellow aspect with more red content, however the shift was too extreme. (The human's perception of colour is very sensitive to small chromaticity changes in this region.)

Another yellow LED, DY5, meanwhile became available and, despite a thin yellow dye in the package, appeared to fall between the previous colour extremes. (The package color is probably only for device identification). Its chromaticity co-ordinates were measured (Appendix B) and found to lie about the middle of the existing AAR standard. These devices were thus used for prototypes 4 and 5, circumventing further need for colour mixing.

4.2.2 Other Colour LEDs

To date, no better green LED than the DG1 device used in phase I has been found. As reported in the committee minutes, its apparent colour is reasonable at range, but changes close-up; its chromaticity is also outside the AAR specification. All prototypes have utilized this LED.

The choice of red LEDs is wide; however, most prototypes use the DR1 device to conserve board area, since low numbers are needed compared to the other colour LEDs. It is possible that the less costly DR2 device would provide an economic advantage in a balanced-output, shorter range signal. Because prices of high-brightness LEDs are still falling (and are likely to continue to do so) the choice of which red LED to use was not considered critical.

5.0 TYPE II PROTOTYPES

The type II concept involves the use of a supplementary lense on each LED and a physically spread-out (planar) array, wherein each LED/lense system is focused into the same narrow beam (ideally ±1½°). (N.B. this idea was called "concept 3" in the phase I report (TP5452E), and discussed in section 9.0). Colours of LED's would be scattered throughout the array, and it would look much the same as the Type I when viewed externally.

Effort on type II was displaced by additional type I experimentation during this phase of the project, as is reflected in the Steering Committee minutes. The possibility of obtaining specially-molded lense arrays turned out to be very costly, as did having non-spherical (elliptical) lenses machined and polished. Thus, when it was decided to re-emphasize type II, Davis adopted the approach of utilizing off-the-shelf glass lenses placed in an array approximately 23 cm by 23 cm (see figure 2). This turned out to be a useful approximation at reasonable cost to what might be obtained by an optimized design.

The various LED's evaluated for both type I and type II along with their specifications can be found in Table 1.

5.1 TYPE II MATRIX

Matrix analysis of the type II was done early in the project and the results can be found in Appendix A. The summarized recommendations for type II were as follows:

"The prototype should consist of an array of about 200 LED's arranged in a hexagonal close-packed square uniform pattern of three colours. The LED's will be aligned by their body leads in the printed circuit board. The LED's used will be DR1 red, DG1 green and DY1 yellow (See Table 1). The LED's each will fit in a custom made ellipsoidal lens made of plastic. These lenses should be aligned y body reference in combination with their individual LED's alignment. The existing hot spot accessories should be used if possible."

These recommendations were not as firmly based in experimentation from Phase I of the project as were those for type I. Thus some changes were to be expected as the first prototype was built and tested.

PROTOTYPE NUMBER	LEDs	LENSE	RANGE	COMMENTS
0	31 Red DR2 27 Y DY1 27 G DG1	72 mm Ø -95 mm f.l.	not measured consistent with other prototypes	- Red signal greatest range, ∿ 1 mile; other less than half (model 11 of phase I)
1	42 R DR1 42 Y DY1 37 G DG1	94 mm Ø -116 mm f.l.	R > 1800 m. Y ∿ 500 m. G ∿ 500 m.	- decided to increase number of LEDs for subsequent prototypes.
2	33 R DR2 69 Y DY1 14 O DO1 83 G DG1 199	94 mm Ø -116 mm f.l.	R 1200 m. Y ∿ 800 m. G ∿ 800 m.	- yellow and orange LEDs lit simultaneously for yellow aspect
3	19 R DR1 83 O DO1 97 G DG1	94 mm Ø -116 mm f.l.	R > 1200 m. Y ∿ 800 m. G ∿ 800 m.	- "amber" LEDs used for yellow aspect; judged too reddish - Y,G judged only marginally visible at 800 m.
4,5	19 R DR4 83 Y DY2 97 G DG1	94 mm Ø -116 mm f.l.	R > 1200 m. Y > 400 m. G ∿ 800 m.	- "final" Type I prototypes with larger lense and new yellow LEDs.

Table 2 Type I Prototypes

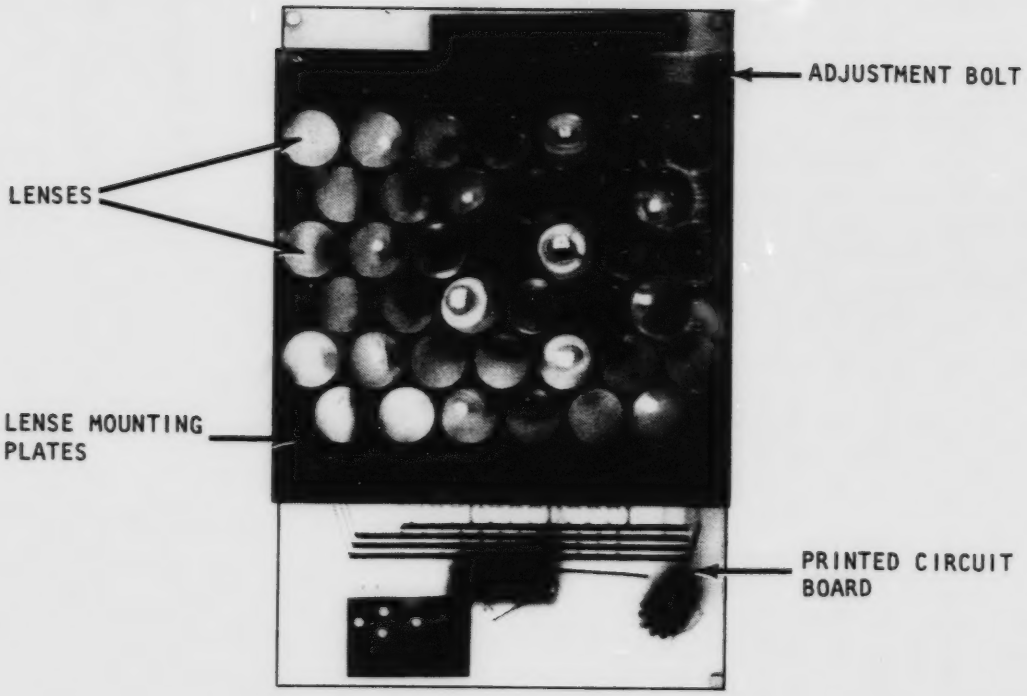


FIGURE 2 TYPE II ARRAY

5.2 TYPE II PROTOTYPE

5.2.1 Optical Design

Placing a simple convex lense in front of an LED, at approximately its focal point, will result in a more-or-less collimated output beam. For efficiency, the lense should be large enough in diameter to capture most of the light, and the LED should be far enough from the lense to approximate a small source. Naturally, as the LED/lense spacing (= lense focal length) increases, the lense diameter also must increase to intercept most of the light. As each lense diameter increases, the number that can be packed in a given frontal area diminishes. However, as diameter and focal length increase, the output beam narrows and fewer LEDs are needed for a given luminance (brightness).

The above are fairly complex interrelations, and it was decided to approach them with relaxed formality. For the sake of assembling a type II within time and financial budgets, it was assumed that an array of 39 LEDs (12 Red, 12 Yellow, 15 Green) would provide sufficient fill and balance to be useable, and enough output to estimate range. This number permits individual lenses of 25 to 40 mm. diameter to be considered.

Examining the beam angle and apparent source size of the various LEDs used in the array, it appeared that a 30 mm. diameter lense would collect most of each LEDs light with the LED set back 60 mm. Geometrically, the LED subtends about 4°, which is equivalent to the desired output beam angle. A single-lense test module (figure 3) was constructed to test this concept with various LEDs, and to determine the effective focal distance. (This is somewhat altered by the LED package lense, but turns out to be quite close to the lense-to-chip distance.)

5.2.2 Array Design

Extension of the concept to an array is straightforward; a sheet of lenses is spaced parallel to a sheet of LEDs,

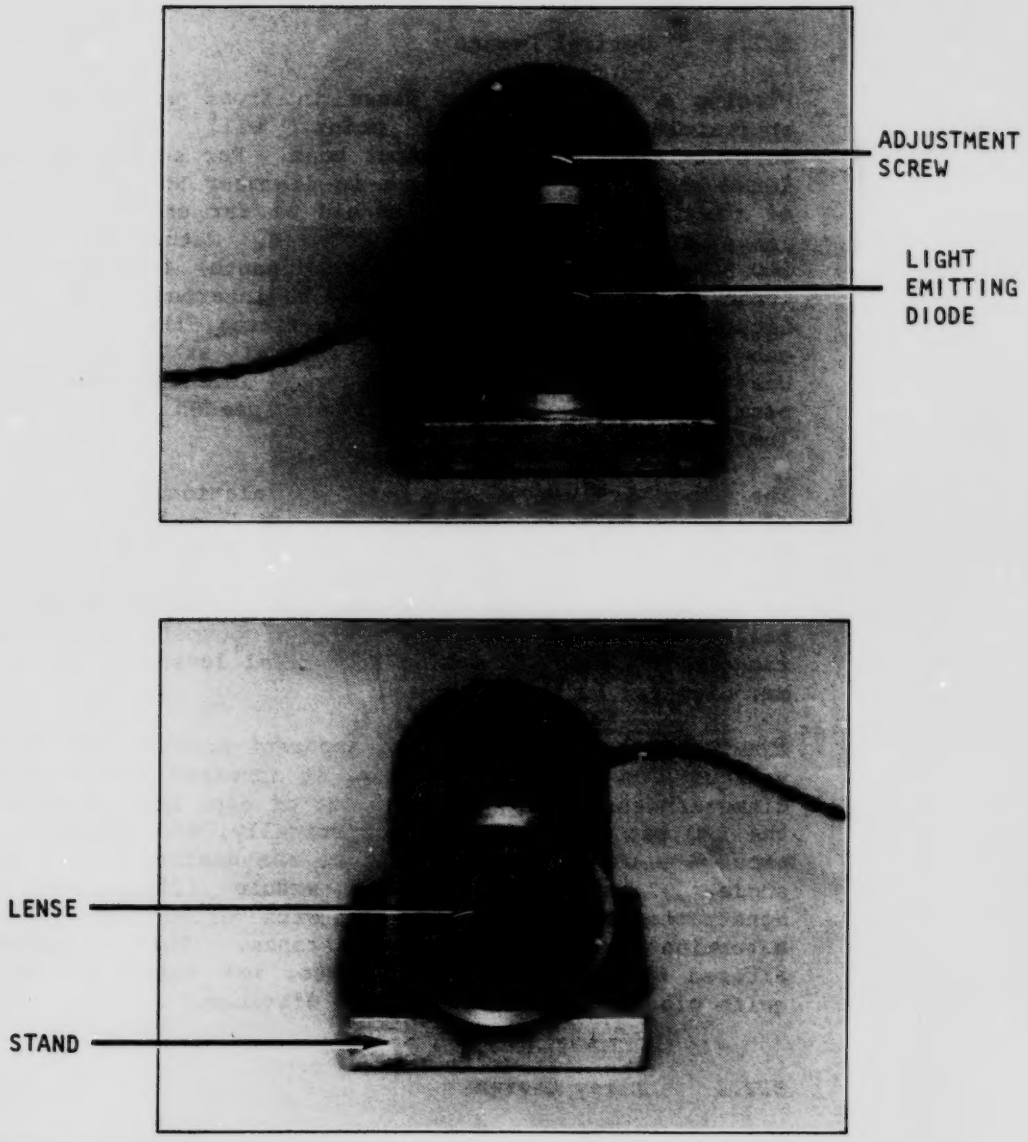


FIGURE 3 TYPE II: SINGLE LENSE TEST MODULE

both centered equally. A hexagonal packing scheme (adjacent rows displaced by one-half a lense diameter) allows higher density. Each LED/lense system projects a collimated, 4° beam; the individual beams start by being displaced over the face of the 9" square, but soon overlap sufficiently that all are seen simultaneously (i.e. beyond 15 feet). Provided the lense plane is flat, and reasonable tolerances are observed on centering the LEDs under their respective lenses, all emergent beams remain combined and the total beam width remains narrow, as desired.

Unlike conventional lamp/lense systems, the collimated LED beam displays even luminance (brightness) throughout its width, dropping very rapidly at the edges. This effect appears to be a result of the area nature of the LED source, and holds up well visually in the full array.

The LED plane is formed from a printed circuit (figure 4) which also has provision for chaining diodes, providing current limiting resistors and (if needed) electronic regulation.

The lense board consists of two aluminum sheets; lenses are cupped in milled cavities in a 5/32" thick plate, and a 1/16" cover sheet is bolted over them as a retainer (drawings # 2721,2722). Lenses used were image-quality 30.0 mm. by 60.0 mm. focal length plano-convex; these were much better quality than necessary, but available in reasonable time (8 weeks).

For experimental purposes, no surrounding enclosure was fabricated. The lense board was spaced from the LED plane by threaded rods, permitting fine focussing. It was found desirable to align each LED to its lense by slightly bending the leads, however this is probably not necessary if a molded LED holder is used.

Due to tolerances in lense thickness and the lense holder, the rigid cover sheet resulted in some lenses being loose, i.e. able to tilt slightly. This would not be a problem in a properly designed production version, as resilience could be built into each cup via an O-ring or the whole could be molded from plastic, with resilient locating nubs.

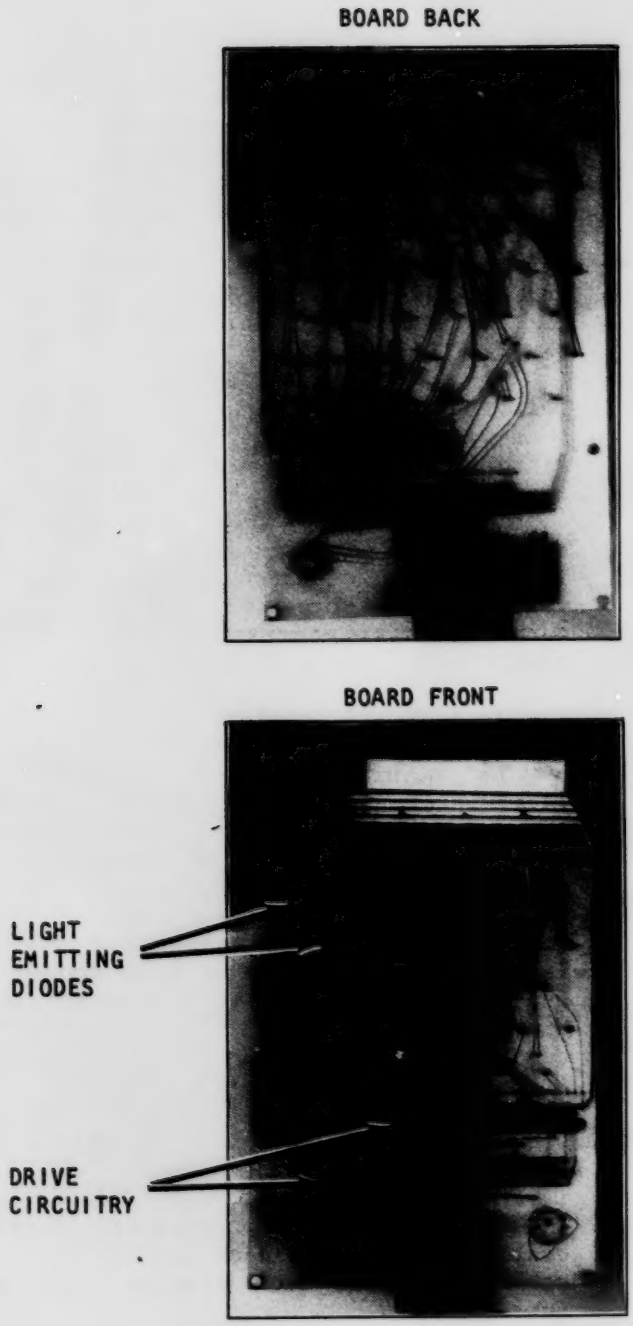


FIGURE 4 TYPE II: PRINTED CIRCUIT BOARD

6.0 ELECTRONICS

It was originally intended that this phase of the project include implementation of an electrical interface between the existing searchlight control and lamp power system, and the LED prototypes. This represented a necessary piece of hardware for retrofit applications, i.e. type I wherein the existing housing and wiring is retained. A preliminary design for this interface was presented in section 10 of the phase I report.

As phase II began, Davis initially sought to obtain the necessary fail-safe design experience through both CN and one of the existing suppliers of rail signal electronics; the rationale was that the field is highly specialized because of the many interactions with other equipment, and the extreme degree of safety that must be assured. Existing suppliers were interested in commercial possibilities and offered to participate, however at the January 10, 1985 Steering Committee meeting it was argued successfully that it might be disadvantageous to be tied to one supplier for an essential component.

In replacement for this resource, CN Rail agreed to provide collaboration with their personnel and Davis, to define the design rules to be followed for fail-safeness. Mr. Ron Nichol, CN Engineer Terminal Systems signals and Communications, met with Davis engineers in March for this purpose.

The original goals for solid-state search light electronics are detailed in the decision analysis (Appendix A) and summarized here:

a) must have the environmental integrity to survive on the railroad;

b) should be compatible with existing power and control signals;

c) must require less maintenance than existing searchlights;

d) should be designed as a "failsafe" system.

With the change in emphasis of Phase II to include more development prototypes of searchlights, the electronic interfacing allotment was cut back. This area was not expected to require any new technology or unconventional design so it was appropriate to postpone it in favour of the more critical area of improving the visual aspects. The solid-state lights still needed drive electronics but the requirements (in (b) above) were relaxed to allow the interface to consist of three twelve volt signals, one for each colour, switched externally. The requirements of both (a) and (c) above were unchanged.

The failsafe issue was resolved after a very informative discussion with Ron Nichol at which CN's current thinking on failsafe design was explored. It was learned that CN has already developed a failsafe searchlight controller which could be adapted to the solid-state searchlight approach provided these were feedback signals to indicate what colour(s) were on. Providing feedback is fairly straight forward so it was decided that detailed design would wait until the next phase when the CN controller should be available.

The prototypes provided operate for supply voltages at 11.6 to 24 volts dc. At 12 volts dc the power requirements are approximately:

16 Watts for Green
14 Watts for Yellow
4 Watts for Red.

7.0 TESTS AND RESULTS

Testing of the prototype units was almost exclusively visual, since this is the existing criteria for current signals. Recognizing the human vision system's ability to adapt in subtle and complex ways, as much testing as possible was performed through side-by-side comparison or matching techniques.

The overall results for each prototype has been summarized in table 2 of section 4.0. Further detail is provided below.

7.1 VISUAL TEST METHODS

It was rapidly recognized that the AAR range specifications, i.e.,

> "Range shall be the distance on a tangent at which, under bright sunlight conditions and with the sun at or near the zenith, the aspects are clear and distinct to a person with normal vision."

was open to interpretation and large variability, and also presented practical problems due to weather dependance. To alleviate this, LED range tests were always carried out side-by-side with a conventional Searchlight signal, with convenient arrangements to switch between signals and colours, and provision to monitor and adjust the lamp voltage.

This strategy was only partly successful; the conventional signal provides a good colour reference, but different aspects have differing luminances and different ranges. Also in many tests the LED luminance was substantially lower and it was visually difficult to assess its range side-by-side with a brighter signal.

Tests were carried out along the edge of a long, straight section of rural road, and it was considered impractical to move the reference signal separately from the LED test signal, (for example, setting the reference to full range for a particular colour aspect and then moving the LED unit until a match occurred). Each movement would have necessitated re-alignment, which can be error-prone and time-consuming, and the signals would subtend differing visual angles, which would bias the comparison.

To circumvent these problems, the following stratagem was developed:

1) the conventional searchlight was considered to have a one mile (1600 metre) range for its weakest aspect (green), which was observed at 1600 m.

2) a series of optical stops (masks) was fabricated in 10% area increments, with additional 5.0% and 2.5% stops. These consisted of black hardboard with radial pie-shaped openings, and could be easily slid into position in front of the reference signal's outer (objective) lense (see figure 5). They reduced the signal's luminance without colour shifts, in a calibrated and repeatable manner.

3) it was determined visually which mask provided a 1600m equivalent signal at 1200, 800 and 400 metres. Within the limits of accuracy of visual memory, these were:

1200 m. - 50% transmittance
800 m. - 40% transmittance
400 m. - 10% transmittance

(The results appeared repeatable within the 10% mask increment.)

4) the revised test method was thus

(a) stop down the reference signal to provide a 1600m equivalent reference for the range under test,
(b) compare the LED signal to the reference, and
(c) estimate and record how much brighter or less bright the LED signal was.

This method resulted in comparing two sources of about equal brightness at each of the test distances, and a much more definitive estimate of "range". It also became much easier to separate colour and brightness effects, and to test during periods of broken cloud cover or changing sun angle. This method is the basis of the range figures given in Table 2.

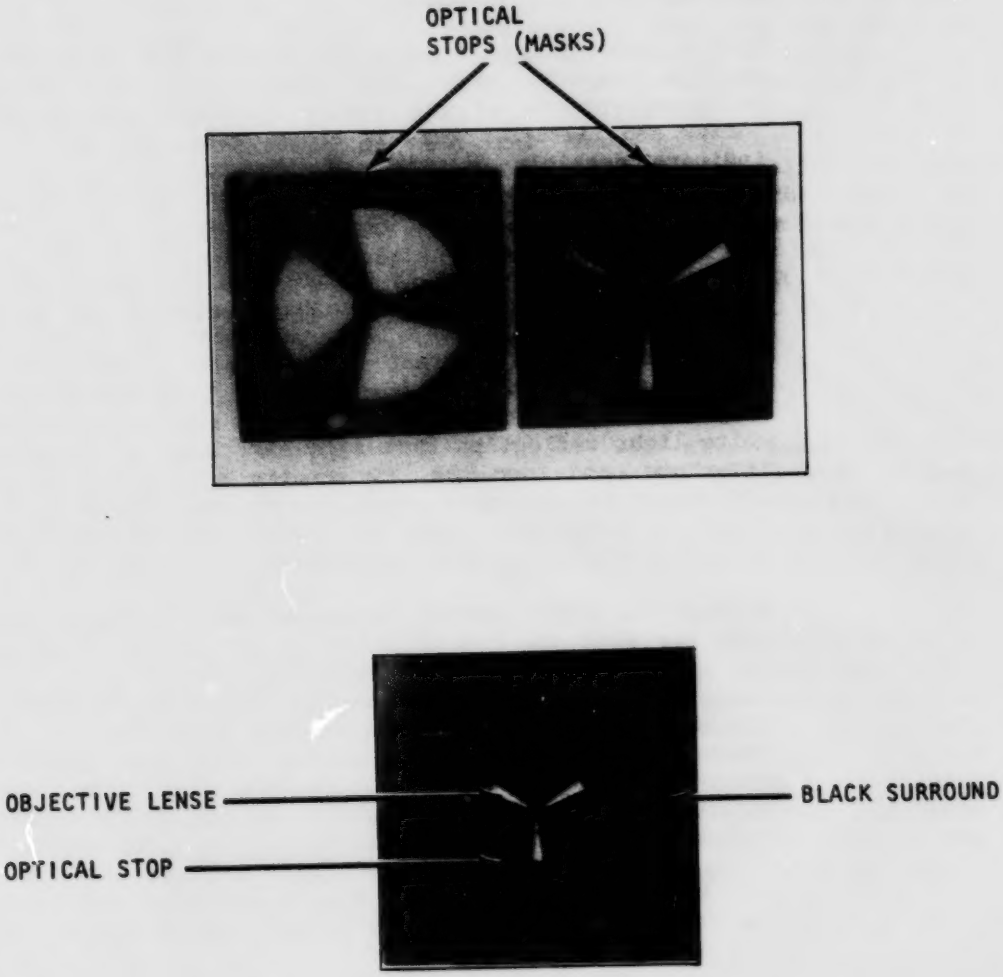


FIGURE 5 CONVENTIONAL LIGHT: TESTING APPARATUS

7.2 PHANTOM TESTS

With a conventional signal, it is possible to observe a phantom aspect when the lamp is off, due to retro-reflections of the engine headlamps from mirrors, lenses and filters. This is undesirable, and may further indicate possible dilution of the colour in a normal working signal, and is usually minimized by the design of the optics.

LEDs should not be capable of creating coloured phantoms, since there are no inherent colours matching the emitted colour (although some LED packages are dyed for identification or contrast enhancement). There is also minimal use of mirror optics; the bowl surrounding the LED chip is the sole exception. There is some possibility of white-light reflection from each air-glass or air-plastic interface, and from the LED substrate material. If the LED array is on, this would dilute the colour; if the array is off, the white reflection is unlikely to be misinterpreted as a legitimate aspect.

Because the signal output is narrow beam, the most severe test for phantoms and dilution is to project light into the signal along its axis, and also observe close to the axis. (This is comparable to observation from an approaching locomotive.) To conduct this test, a clear (white light) colour light signal head was positioned facing into the LED signal optics from about 10 m., and an observer positioned immediately behind it. A second person re-aligned the LED signal slightly to obtain the worst reflection. Comparisons were made to the standard searchlight signal, and the results briefly described at the fourth Steering Committee meeting (April 23/85).

7.2.1 Type I

Although no coloured phantoms could be induced for type I, initially a very strong retro-reflection was visible over a very narrow angle. This was traced to the plane air-glass surface of the interior (plano-concave) lense, which was mounted with the plane side facing the LEDs. External light entering the system exactly on-axis impinges on this surface normally (90°), across the whole surface. When the lense was rotated side-for-side, this situation did not exist and the reflection disappeared.

There are two approaches possible to avoiding this with type I: orient the plane surface away from the LEDs, or use a double-concave lense with no plane surface. The plano-concave lense was initially selected because it traditionally is used for collimation, having slightly less distortion, and the same reasoning applies to orienting its plane surface towards the collimated beam (i.e. the LEDs). In this application, neither factor is major because far more severe departures from ideal optics exist, for example, the light from the LEDs is not well-collimated. Prototypes numbers 4 and 5 thus use double-concave lenses to avoid reflections.

7.2.2 Type II

The prototype type II array was also assembled with plano-lenses, (plano-convex, with the plane side towards the LEDs), however no major reflection was observed. Weak reflections from the lense holder, which was unfinished aluminum, were present but would be easily avoided using black paint.

Examination of the optical path of the type II shows that, with the plane side of the lenses facing the LEDs, external light does not encounter a substantial area of normal (90°) air-glass interface, i.e. the collimated, external incident light never sees a large, flat reflector at one specific angle. Since utilization of a plano lense correctly oriented does not present a problem, and since each optical path is more nearly "correct" than in the type I case, there is no compelling reason to use a different lense shape.

8.0 DISCUSSION

8.1 GENERAL COMMENTS

This phase of the project began with a detailed analysis of the various alternatives available in the design of both type I and type II searchlight array prototypes as well as the electronic smart box. This decision analysis (Appendix C) was intended to determine the optimum design. In combination with further experimentation and discussion with CN the final prototypes of this phase were designed and manufactured.

The electronic smart box was not manufactured after discussion with CN indicated that their own failsafe signal controller would be adaptable to a solid state searchlight. The electronics provided for type I prototypes only include those required to drive the LEDs with some regulation to compensate for supply voltage variations and some protection against voltage surges. The array driver meets railway specifications for reliability and operating temperature. Schematics and board layouts for type I are included in Appendix D.

Two type I prototypes are provided, one with a bracket suitable for use in the GRS Co. Ltd. housing. All mechanical drawings can be found in Appendix D.

One type II breadboard prototype was made. It is not production quality or an optimized design but is intended for technical evaluation only. This prototype is very promising in terms of light output and warrants further development. Schematics, layout and mechanical drawings can be found in Appendix E.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

Phase II of the project to develop a solid-state replacement for a three-colour searchlight signal exceeded the minimum range requirements (400 m) and succeeded in demonstrating two viable optical approaches. We conclude that:

(1) LED technology is today capable of at least 800 m range in full sunlight;

(2) red LED technology is most advanced in brightness and efficiency, with comparable yellow and green LEDs still a year or two away;

(3) Although a blue-green LED able to meet the AAR/CIE chromaticity specification is not now known to be on the market, development is ongoing and it is expected to be available soon. (The consequence of this lacking, especially in a population screened for normal color vision such as the railways, is debatable, but the specification exists.)

(4) Individual-lense-per-LED optics is inherently capable of narrower beamwidths (and thus higher brightness) than single-lense, multi-LED arrays.

9.2 RECOMMENDATIONS

LED technology is key to railway signalling and other outdoor, long range visual applications. The performance of the red LEDs represents what will probably be available in the near future in other colours. Even the achievement of a bright, internationally-accepted green LED is just a matter of time, and is assuredly an important goal for LED manufacturers. Thus, in addition to colour signal applications covered by the currently-achieved performance, project results provide a head start for a full range of completely equivalent or superior signals.

Recommendations fall into two broad groups: those immediately feasible, and those requiring further technology such as LED improvements. For the immediate future, we recommend (in priority):

(a) development of all-red applications, for example at grade crossings or to replace the separate,

single colour lights on a one-for-one basis, for example in traffic light or railway colour light stacks. LEDs will provide equivalent or better range at a fraction of the power and will be maintenance-free and ultra-reliable.

(b) development of compact, short range colour signals, especially for environments where the lack of the Standard green is an acceptable trade-off for reliability, maintenance and power savings. (One example would be signalling within a switchyard, where short range is desirable.

(c) development of non-colour dependent signal applications, for example various transportation markers and flashers, where the low power consumption, ruggedness and reliability of LEDs is valuable.

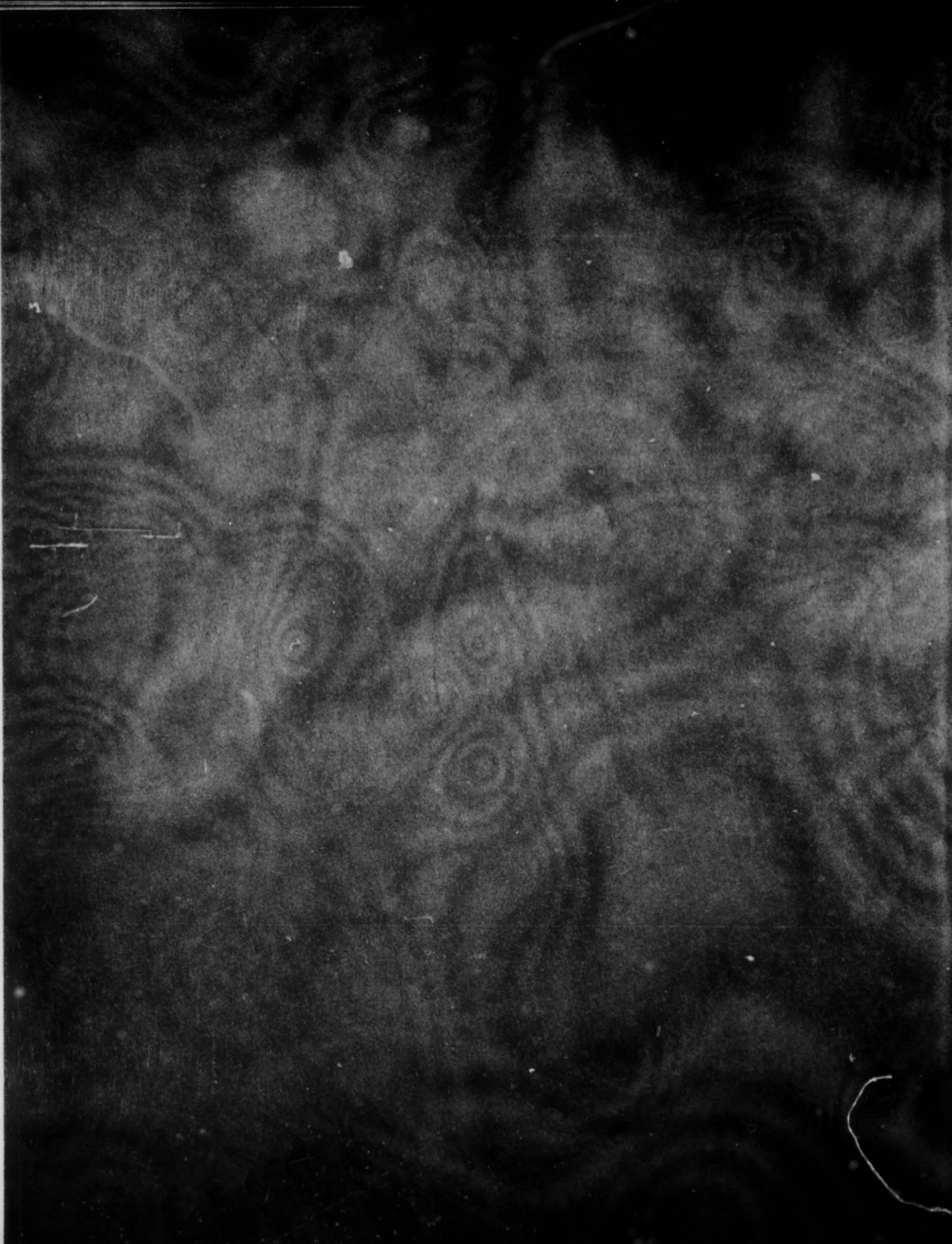
(d) exploration of the visual effectiveness gained by exploiting the unique abilities of LEDs to be modulated, colour switched and arranged in shapes. (Existing standards, developed around filtered tungsten light, have deferred much consideration of these possibilities in the current project.)

(e) An explicit plan for following and evaluating the planned visual tests of the prototypes by CN Rail should be generated. Undoubtedly LED technology will have progressed and an extrapolation of the effect of brighter LEDs and/or other colours will be worthwhile.

To anticipate future improvements in LED technology, research is strongly recommended on (in priority):

(f) Semiconductor processing to achieve wavelengths falling within the AAR/CIE specifications for green, and

(g) Further improvements in the optical efficiency of LEDs combined with lenses, for example the custom fabrication of dense, multi-LED arrays to provide better point sources for conventional projection optics.



APPENDIX A

PHASE II - DECISION ANALYSIS

RAILWAY COLOUR SIGNAL LIGHT

PHASE II

DECISION ANALYSIS

Revised as per

Client's Instructions

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MARCH 1985

DECISION ANALYSIS

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DECISION ANALYSIS

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OBJECTIVES OF USING DECISION ANALYSIS

The Kepner-Tregoe (K-T) decision analysis technique is a technique which allows the sorting of various solutions for a particular problem in a systematic fashion. It allows the objectives in solving the problem to be clearly stated and weighed. The alternative solutions are scaled for their ability to meet each objective. Using the weights and scales a quantitative indication of each alternative's merits and shortcomings is obtained.

From Phase I of the project it became apparent that there are many alternatives possible in the design of a replacement LED array for railway color signal lights. K-T decision analysis has been used to help sort out these alternatives. It does not result in a complete design of the array but offers guidelines. It also eliminates alternatives which become obviously unsatisfactory.

TECHNIQUES AND FORMATS

The techniques of K-T decision analysis is summarized below.

A decision is that best choice of a course of action to achieve objectives. Making that choice requires decision analysis.

ESTABLISH OBJECTIVES

Identify the **Results** to be accomplished and the relevant **Resources** that need to be considered for this decision situation.

CLASSIFY OBJECTIVES

MUST

A class of objectives (result or resource) so critical to this decision situation that they have or require a specific and measurable limit of acceptability which any alternative must satisfy.

WANT

A class of objectives (result or resource) which are weighted for relative importance to this decision situation, and which alternatives may satisfy to varying degrees.

GENERATE ALTERNATIVES

An alternative is a possible course of action. Since a decision is a choice, several alternatives covering a range of actions ought to be considered.

COMPARE ALTERNATIVES

TO MUST OBJECTIVES

Test the information about each alternative "GO" or "NO GO" against the limits established. Eliminate "NO GO" alternatives.

TO WANT OBJECTIVES

For remaining alternatives, compare and weight relevant information to each WANT objective. Reflect the relative weight of WANT objectives.

Select the alternative that satisfies MUST objectives, and WANT objectives.

In order to establish and classify the objectives a sheet of the form on page 3 is used. One is used to summarize the must objectives and a second to summarize the want objectives.

The alternatives are compared on a sheet of the form on page 4. The alternatives are given a score relative to each objective and the weights and scores combined and totaled. The totals are used to determine the best alternative.

MODIFICATIONS TO K-T DECISION ANALYSIS

In order to make the analysis for this project easier and more efficient K-T Decision Analysis has been modified slightly.

First, in considering the alternatives not all of the objectives are listed each time. Instead only those which might not be met are included.

Second, it is often easier to sequence the analysis of alternatives. As an example, the choice of LED packing and alignment of LED's for a Type I array are interdependent. Provided alignment is not made much more difficult by a change in packing it is more efficient to choose the packing first. When this is the case the decision statement will specify the sequencing.

Decision Statement:

Establish and Classify Objectives:
List the important results to be accomplished, resources to be used, and limits to be observed in this decision

Objectives	Relative Importance	Objectives	Relative Importance

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decision statement

objectives whatever I choose should:		alternatives a			b		
must		info	go/no		info	go/no	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
		total					

SCALES

The objectives weighted on a scale from 1 to 10 with 1 being a low importance objective and 10 being a must objective. Since the objectives are independent the scale is not quantitative.

The alternatives are scored on a scale from 0 to 6 with 0 being a low score and 6 being a perfect score. In some cases numerical analysis has been possible and the scores are quantifiable. Otherwise they are qualitative with the scores roughly corresponding to the following:

6 - Perfect
5 - Great
4 - Good
3 - Acceptable
2 - Poor
1 - Bad
0 - Unacceptable

AREAS OF MATRIX EVALUATION - TYPE I

The various alternatives have been grouped into three main categories: LED's, Optics and Mechanical. These are further divided as shown below:

MAIN CATEGORY	SUB CATEGORY	ALTERNATIVE
LED's	Red	DR2, DR1, DR3
	Green	DG1, DG2, Green with blue, Wait for correct chromaticity
	Yellow	DY1, DY2, DY3, DY4, Wait for correct chromaticity
Optics	Type	Plano-concave, double concave, other
	Material	Glass, Plastic
	Manufacture	Molded, ground

MAIN CATEGORY	SUB CATEGORY	ALTERNATIVE
Optics (cont'd)	Shape	Round, Hexagonal
	Patterns	Different pattern for same color different meaning, One pattern per color maximized for recognition of pattern, Pattern for luminance maximized and uniformity
Mechanical	Packing	Close pack, deflange & close pack, use fewer less closely packed, close pack some and not others
	Alignment	PC lead, alignment overlay, body reference

RANGE FORMULA FROM METER READINGS

In phase I of the project two meters a Soligor meter and Tektronix meter were used to measure the relative intensity of the existing light and various prototypes. The Soligor meter and Tektronix meters gave dissimilar graphs when plotted indicating that they were not measuring the same thing. Further investigation showed the Soligor meter to be non-linear in measuring foot-lamberts of intensity. The Tektronix was therefore taken as the standard for measuring the relative intensity of the existing light and any new array.

At the time an array of:

31 Red 500 mcd LED's
27 Yellow 140 mcd LED's
27 Green 200 mcd LED's

gave a ratio of

Red 86
Yellow 72
Green 30

for Intensity in foot-lamberts of the $\frac{\text{CN light}}{\text{Array}}$.

From this information it is possible to develop a rough formula which will allow some quantitative values for range in the decision analysis. The formula is not intended to be precise but to act only as a guideline for decision analysis.

Based on the above data the formula is:

$$\frac{Z_o \times I_o}{Z_n \times I_n} \times C_c = \frac{1320^2}{X_c}$$

Where Z_o is the number of LED's in the prototype standard.

Z_o = 31 for red
= 27 for yellow
= 27 for green

Z_n is the number of LED's in the new array.

I_o is the intensity of each LED in the prototype standard.

I_o = 500 mcd for red
= 140 mcd for yellow
= 200 mcd for green

I_n is the intensity of each LED in the new array.

C_c is the constant for each colour.

$C_r = .6$

$C_y = 5$

$C_g = 2$

X_c is the distance required to compare with the CN light at 5000 ft.

FORMULA RELATING BEAM WIDTH AND ARRAY SIZE

In Phase I the following formulas for optimizing r were presented. Without doing further development here it can be seen that the array size will depend on r. Also if r is changed for LED's of a given α the beam width Δ will change also. This results in a loss or gain of range depending on the change in r. Since Δ must be equal or greater than 2° there is a minimum r for a given α. These formulas can be used as a guideline for determining how array size (packing) affects the range.

Decision Statement: TO CHOOSE THE OPTIMUM TYPE I ARRAY PROTOTYPE

Establish and Classify Objectives:
List the important results to be accomplished, resources to be used, and limits to be observed in this decision

Objectives (MUST)	Relative Importance	Objectives	Relative Importance
1 Minimum Range of 1320 feet	10	13 Suppression of phantom aspects	10
2 Three required colours	10	14 Maintenance period of at least one year	
3 No moving parts	10	15 One lens for all LED's, i.e., not a separate lens for each LED	10
4 Fit existing outer housing (retrofit)	10	16 Reliability (20 year life span)	10
5 Minimum Beamwidth of ±2°	10		
6 Light emitting surface completely fill 8 3/8" diameter outer lens	10		
7 Redundant configuration of each colour	10		
8 Power Consumption _ 18 Watts	10		
9 Materials and Workmanship to ARR Specifications	10		
10 Operate over -40°C to 70° normally	10		
11 Withstand shock, vibration and humidity etc. as expected in railway environment	10		
12 Use existing beam spreading, deflecting & hot spot accessories	10		

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TYPE I ARRAY - TO CHOOSE THE OPTIMUM TYPE I ARRAY PROTOTYPES

OBJECTIVES

Main

The main objectives are based on the design guidelines and the work statement for prototype development. They include the steering committe's comments on the preliminary draft.

Want

These are based on the design guidelines, work statement for prototype development and the CN searchlight specification and design recommendations. They are clarified below.

1a Range of 5000 feet

This would allow complete interchangeability of Type I prototypes and existing searchlight. The requirement for 1320 feet is a minimum with 5000 feet as a desirable upper limit. The main criterion here is that the array be visible at 5000 feet.

1b Range of 2500 feet

This would allow interchangeability of Type I prototypes and existing searchlights in certain applications. The requirements for 1320 feet is a minimum with 2500 as a desirable upper limit. The main criterion here is that the array be visible at 2500 feet.

2a Correct Chromaticities

The AAR specifications for the chromaticity should be met if possible. There are not yet available LED's of sufficient intensity to realistically meet these requirements. The development of prototypes however can incorporate LED's of the correct chromaticity when they become available provided they have similar electrical characteristics.

2b Color Distinguishability

There should be no confusion of colors, i.e., yellow for green and green for yellow. This is related to the chromaticity of the LED but also to the intensities and/or relative intentsities of each color.

3 Minimize Power Consumption

Since provision of site power is costly, the maximum power consumption of 18 watts is a limit and a lower value is desirable.

4 Minimize Cost

Cost here includes material costs, assembly costs and the capital costs such as special tools, moulds, etc. The expected cost of manufacture of the prototype should meet the budget of $2,300 per unit and less if possible.

5 Manufacturability

Since these prototypes are intended eventually to be a production item they should meet requirements of repeatability, manufacturing tolerances at minimum cost, Considerations here are the cost of machining, cost for reproducibility and the cost of specially manufactured parts such as lenses.

6 Shape of Pattern

The pattern shape should be circular such that it does not cause confusion and allows use of existing accessories. The main criterion here is distinguishability of colours.

7 Uniformity of Pattern

This allows ease of failure recognition and also gives better optical characteristics when uniform.

8 Information of Pattern

One colour could convey more than the usual information through pattern changes or low frequency modulation.

9 Maintainability

Once built and tested there should be ease of access to failing components, ease of replacement, in field testing capability and in field focussing and alignment.

10 Maximize Beamwidth

A wider beamwidth allows the light to be seen over a wider angle (eg. curves).

11 Mean Time between Failures greater than One Year

A long service life is desirable and of importance is predictably of failure and the degree of failure.

12 Separate LED's for each Required Color

It is undesirable to have color mixing since confusion of colors can result should failures occur. Also the color mixing is only effective over certain ranges. Close to the light the mixed colors become visibly seperable.

13 Complete the prototype stage by June 1985

It is desirable to complete the prototype stage so that the field testing can begin. This is a target date only.

Decision Statement: TO CHOOSE THE OPTIMUM TYPE I ARRAY PROTOTYPE

Establish and Classify Objectives:
List the important results to be accomplished, resources to be used, and limits to be observed in this decision

Objectives	Relative Importance	Objectives	Relative Importance
1a Range of 5000 feet	5	11 Mean time between failures greater than one year	9
1b Range of 2500 feet	9	12 Separate LED/s for each required colour	7
2a Correct Chromaticities	9	13 Complete the protoype stage by June 1985	7
2b Colour distinguishability	9		
3 Minimize Power Consumption	6		
4 Minimize Cost (budget 2300/unit)	5		
5 Manufacturability	7		
6 Shape of Pattern	2		
7 Uniformity of Pattern	4		
8 Information of Pattern	1		
9 Maintainability	8		
10 Maximize Beamwidth	3		

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TYPE I - LED's

decision statement TO CHOOSE THE BEST LED's (COLOUR RED)

objectives whatever I choose should:		alternatives a DR1			b DR2		
must		info	go/no		info	go/no	
1 Range of 1320'			✓			✓	
16 Reliability (20 yr. life span)			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	2000 mcd, 12°	5	25	500 mcd, 12°	3	15
1b Range of 2500 feet	9	200 mcd, 12°	6	54	500 mcd, 12°	5	45
2a Correct Chromaticities	9	within AAR specs	6	54	within AAR specs	6	54
2b Colour distinguishability	9	clearly red	6	54	clearly red	6	54
4 Minimize Cost	5	approx. 12.50 each	3	15	approx. 1.00	5	25
10 Maximize Beamwidth	3	12° beamwidth	3	9	12° beamwidth	3	9
13 Complete the protoype stage by June 1985	7	possible	6	42	possible	6	42
				253			244

alternatives								
c DR3			d			e		
info	go/no		info	go/no		info	go/no	
	✓							
	✓							
info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
500 mcd, 12°	6	30						
5000 mcd, 12°	6	54						
within AAR specs	6	54						
clearly red	6	54						
approx. 50 each	0	0						
approx. 12° beamwidth	3	9						
not available	0	0						
	201							

TYPE I - LED's

decision statement TO CHOOSE THE BEST LED's (COLOUR YELLOW)

objectives whatever I choose should:		alternatives					
		a DY1			b DY2		
must		info	go/no		info	go/no	
1 Range of 1320'			✓			✓	
16 Reliability (20 yr life)			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	140 mcd, 24°	2	10	dpprox. 125 mcd, 24°	1	5
1b Range of 2500 feet	9	140 mcd, 24°	3	27	dpprox. 125 mcd, 24°	2	18
2a Correct Chromaticities	9	583 nm	4	36	approx. 580 nm	3	27
2b Colour distuishability	9	fair	4	36	fair	2	27
4 Minimize Cost	5	approx. .70 each	6	30	approx. 1.00 each	5	25
10 Maximize Beamwidth	3	24° beamwidth	5	15	24° beamwidth	5	15
13 Complete by June 1985	7	possible	6	42	possible	6	42
				196			159

alternatives								
c Wait for Correct Chromaticity			d DY3			e DY4		
info	go/no		info	go/no		info	go/no	
	/							
	/							
info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
< 140 mcd, 24°	1	5	350 mcd, 24°	3	15	500 mcd, 12°	4	20
< 140 mcd, 24°	2	18	350 mcd, 24°	4	36	500 mcd, 12°	5	45
within AAR specs	6	54	570 nm	2	18	unknown	3	27
clearly yellow	6	54	fair	2	18	poor	5	45
expensive	3	15	approx. $1.00	5	25	expensive	2	10
approx. 24° beamwidth	5	15	24° Beamwidth	5	15	approx. 12° beamwidth	3	9
unavailable	0	0	possible	6	42	unavailable	0	0
		161			169			156

TYPE I - LED's

decision statement TO CHOOSE THE BEST LED's (COLOUR GREEN)

objectives whatever I choose should:		alternatives a DG1			b Wait for Correct Chromaticity		
must		info	go/no		info	go/no	
1 Range of 1320'			✓			✓	
16 Reliability (20 yr, life)			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	200 mcd, 24°	2	10	∠ 200 mcd	0	0
1b Range of 2500 feet	9	200 mcd, 24°	3	27	∠ 200 mcd	0	0
2a Correct Chromaticities	9	555 nm	1	9	Within AAR specs.	6	54
2b Colour distuishability	9	poor	2	18	clearly green	5	45
4 Minimize Cost	5	$1.38	5	25	expensive	2	10
10 Maximize Beamwidth	3	240 beamwidth	5	15	unknown	3	9
13 Complete by June 1985	7	possible	6	42	not yet available	0	0
				146			118

alternatives								
c DG2			d DG1 with blue			e		
info	go/no		info	go/no		info	go/no	
12°	/			/				
	/			/				
info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
200 mcd, approx 12°	3	15	Blue are approx. 5 mcd	1	5			
200 mcd, approx 12°	4	36	approx 5mcd for blue	2	18			
560nm	1	9	better than existing green	3	27			
poor	2	18	better	3	18			
approx. $ 1.50	5	25	expensive	1	5			
12°	6	18	unknown	3	9			
not yet available	0	0	not yet available	0	0			
	121			82				

TYPE I - LED's - TO CHOOSE THE BEST LED's

1a Range of 5000 Feet

Intensity of the LED (given in millicandlas) is the main consideration here. Also important is the half intensity angle of the LED and to a lesser degree the chromaticity of the LED. Obviously greater intensity means greater range. The half intensity angle relates to the amount of light in a given area. A narrower beam means greater range. The eye also sees lights of the same absolute intensity differently for different colors. This is particularly true of green in this case.

1b Range of 2500 Feet

The same criterion as are used for 1a apply here with the score indicating the ability to reach the 2500 foot range only.

2a Correct Chromaticity

The AAR specifications for chromaticity were used.

6 was given if these specifications were met.

5 to 1 were given for progressively greater distances from these specifications within the general colour character.

2b Color Distinguishability

The chromaticity of the LED's is important here and green is furthest from the AAR specifications. Also important is the relative intensities of the three colors.

4 Minimize Cost

In this case LED's were rated 6 for less than $.80 for production quantities, 5 for $.80 to $3.00, 4 for $3.00 to $12.00, 3 for $12.00 to $50.00, 2 for $50.00 to $200.00 and 1 for $200.00 and up.

10 Maximize Beamwidth

The greater the half intensity angle of the LED the greater the signal beamwidth.

13 Complete the Prototype Stage by June 1985

Waiting for LED's of the correct chromaticity or intensity will not allow this criterion to be met.

TYPE I - LENSES

decision statement TO CHOOSE THE BEST TYPE OF LENS

objectives whatever I choose should:		alternatives					
		a Double Concave			b Plano Concave		
must		info	go/no		info	go/no	
5 Minimum beamwidth of ±2°			✓			✓	
6 Light emitting surface completely fill 8 3/8" outer lens			✓			✓	
13 Suppression of Phantom Aspects			✓		only in one direction	✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	has aberration	2	10	less aberration	3	15
1b Range of 2500 feet	9	has aberration	3	27	less aberration	4	36
4 Minimize Cost	5	OK	3	15	OK	3	15
5 Manufacturability	7	OK	3	21	OK	3	21
10 Maximize Beamwidth	3	has aberration	3	9	less dispersive	2	6
6 Shape of Pattern	2	has aberration	2	4	OK	3	6
7 Uniformity of Pattern	4	has aberration	2	8	OK	3	12
13 Complete by June 1985	7	possible	6	42	possible	6	42
				136			153

alternatives

c Other (eg. change exisitng lens LED)		d		e	
info	go/no	info	go/no	info	go/no
	✓				
	✓				
	✓				

info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
more illuminance	4	20						
more illuminance	4	45						
expensive	1	5						
difficult	1	7						
wider beam	4	12						
stronger on edge	4	8						
minimum distortion	4	16						
not possible	0	0						
		113						

TYPE I - OPTICS - TO CHOOSE THE BEST TYPE OF LENS

1a Range of 5000 Feet

For an object at infinity (the observer at 5000 feet) a plano-concave lens exhibits a minimum of spherical aberration as compared to a double concave lens. In this application any aberration in the lens would result in spreading the beam and hence less range. Custom modifications could be done to the LED's to concentrate the beam into a narrower forward angle which would increase the range.

1b Range of 2500 Feet

The same criterion as are used for 1a apply here with the score indicating the ability to meet the 2500 foot range requirement only.

4 Minimize Cost

There is negligible difference in cost between the double concave and plano concave lenses. Any other option would involve a custom modification which would be very expensive.

5 Manufacturability

There is negligible difference between the ease of manufacturability of double concave and plano concave lenses. The industry and technology for this manufacturing is well established. Any other option would involve the development of new manufacturing tools and procedures.

10 Maximize Beamwidth

This lens by itself cannot increase or maximize the beamwidth. It must provide a focussed beam as required by the front lens (which would spread the beam). The plano concave lens is preferred over the durable concave lens because of its minimum spherical aberration. Custom modifications could result in more focussed light which would help in maximizing the beamwidth.

7 Shape of Pattern

The plano concave lens is preferred over the double concave as the former lens has minimum spherical aberration resulting in minimum pattern distortion. Custom modification could improve the intensity at the edge and hence give a better pattern.

8 Uniformity of Pattern

Because of its minimum spherical aberration, the plano concave lens should give a more uniform pattern than the double concave lens. Custom modification could reduce any remaining distortion to give an even more uniform pattern.

13 Complete by June 1985

Both the plano-concave and double concave lenses can be easily obtained by special order. Modification of the existing lense would have to be done by the manufacturer at prohibitve cost and time limits.

TYPE I - OPTICS

decision statement TO CHOOSE THE BEST TYPE OF LENS MATERIAL

objectives whatever I choose should:		alternatives a Plastic			b Glass		
must		info	go/no		info	go/no	
9	Materials & Workmanship to ARR Specifications		✓			✓	
11	Withstand Shock & Vibration as expected		✓			✓	
16	Reliability		✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a	Range of 5000 feet	5	OK	3	15	clearer	4	20
1b	Range of 2500 feet	9	OK	4	36	clearer	5	45
4	Minimize Cost	5	cheap	4	20	OK	3	15
5	Manufacturability	7	easy	4	28	OK	3	21
8	Uniformity of Pattern	4	OK	3	12	sharper image.	3	12
				111				113

TYPE I - OPTICS - TO CHOOSE THE BEST LENS MATERIAL

1a Range of 5000 Feet

Glass is a clearer material though both would give acceptable ranges.

1b Range of 2500 Feet

The same criterion as are used for 1a apply here with the score indicating the ability to meet the 2500 foot range requirement only.

4 Minimize Cost

Plastic is a much cheaper material than glass.

5 Manufacturability

Plastic is much easier to work with than glass but glass is still the most commonly used material for lens manufacture.

7 Uniformity of Pattern

Glass provides a much better optical quality image, but it is questionable that this would be visually noticeable.

TYPE I - OPTICS

decision statement: TO CHOOSE THE BEST TYPE OF LENS MANUFACTURE METHOD

objectives whatever I choose should:		alternatives					
		a Molded			b Ground		
must		info	go/no		info	go/no	
9 Materials and Workmanship to ARR Specifications			✓			✓	
12 Use existing accessories			✓			✓	
16 Reliability (20 yr. life)			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
4 Minimize Cost	5	expensive	1	5	cheapest	5	25
5 Manufacturability	7	very easy	5	35	difficult	2	14
7 Uniformity of Pattern	4	poor	2	8	good quality	4	16
6 Shape of Pattern	2	acceptable quality	3	6	best image	4	8
13 Complete by June 1985	7	possible	4	28	possible	4	28
				82			91

TYPE I - OPTICS - TO CHOOSE THE BEST LENS MANUFACTURE METHOD

4 Minimize Cost

In prototype quantities the price is much more for molded (the mold cost is spread over only 10 units).

5 Manufacturability

Manufacture is much easier with a molded lens since less grinding and tooling is required.

6 Shape of Pattern

Grounded lenses produce the best image quality of the two methods.

7 Uniformity of Pattern

Molded lenses have poorer quality than ground lenses.

13 Complete by June 1985

Neither molding nor grinding should be prohibitive in terms of time for manufacture.

TYPE I - OPTICS

decision statement TO CHOOSE THE SHAPE WHICH WILL BEST MATCH OPTICALLY WITH THE CHOSEN LENS

objectives whatever I choose should:		alternatives a Round			b Hexagonal		
must		info	go/no		info	go/no	
5 Minimum beamwidth of ±2°			✓			✓	
12 Use existing accessories			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	OK	3	15	OK	3	15
1b Range of 2500 feet	9	some patterns work	4	36	boosts weak colors	4	36
3 Power Consumption	6	OK	3	18	fewer LED's	3	18
4 Minimize Cost	5	OK	4	20		3	15
6 Shape of Pattern	2	best	4	8	OK	3	6
7 Uniformity of Pattern	4	OK	4	16	OK	4	16
8 Information of Pattern	1	OK	4	4	OK	4	4
10 Maximize Beamwidth	3	OK	3	9	OK	3	9
				126			119

TYPE I - OPTICS - TO CHOOSE THE SHAPE WHICH WILL BEST MATCH OPTICALLY WITH THE CHOSEN LENS

1a Range to 5000 Feet

As a result of the number of LED's being very similar the range is not affected by the shape.

1b Range of 2500 Feet

The same criterion as are used for 1a apply here with the score indicating the ability to meet the 2500 foot range requirement only.

3 Power Consumption

The number of LED's and therefore power is nearly the same.

4 Minimize Cost

The hexagonal shape might require a slightly larger lens of closer tolerances.

6 Shape of Pattern

The round shape best fits the optics which are round.

7 Uniformity of Pattern

Both are equally uniform given the same pattern.

8 Information of Pattern

Both will convey the same information.

10 Maximize Beamwidth

Both would have similar beamwidths.

TYPE I - OPTICS

decision statement TO CHOOSE THE BEST PATTERN GIVEN THE PACKING METHOD

objectives whatever I choose should:		alternatives a Different Patterns Same Colour Different Meaning			b One Pattern/Colour max. for Recognition of Pattern		
must		info	go/no		info	go/no	
1 Range of 1320'		possible for Red & possibly green	✓		not relevant at large distances	✓	
7 Redundant Configuration		great care necessary	✓		great care necessary	✓	
12 Use of existing accessories		great cave necessary	✓		great care necessary	✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	some patterns weak	2	10	boosts weak colours	5	25
1b Range of 2500 feet	9	some patterns weak	3	26	boosts weak colors	6	54
3 Minimize Power Consumption	6	more control needed	2	13	OK	3	18
4 Minimize Cost	5	more design, circuitry	2	10	OK	3	15
6 Shape of Pattern	2	complicated, inefficient	1	2	improved discrimination	4	8
7 Uniformity of Pattern	4	non-uniform	1	4	poor pattern	3	12
8 Information of Pattern	1	gives colour & information	5	5	indicates colour	1	1
10 Maximize Beamwidth	3	beamwidth compromised	1	3	some colours narrow	3	9
				73			142

alternatives								
c Pattern for Luminance max. + uniformity			d			e		
info	go/no		info	go/no		info	go/no	
Greatest Range	✓							
Less Care Necessary	✓							
Some Care Necessary	✓							
info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
optimized average	5	25						
optimized average	6	54						
OK	3	18						
OK	4	20						
uniform shape	3	6						
very uniform	6	24						
no information	1	1						
optimized average	4	12						
		160						

TYPE I - OPTICS - TO CHOOSE THE BEST PATTERN GIVEN THE PACKING METHOD

1a Range of 5000 Feet

The eye can only resolve objects at a ratio of 3000 to 1 objects at a distance that is at 3000 feet the eye cannot resolve any detail smaller than a foot. Therefore patterns will not affect the range at distances greater than 1320 feet and if an attempt is made to do so using a variety of patterns the range will be reduced due to the decrease in intensity.

1b Range of 2500 Feet

The same criterion as are used for 1a apply here with the score indicating the ability to meet the 2500 foot range requirement only.

3 Minimize Power Consumption

This is affected only by the control required to run the array.

4 Minimize Cost

In a) the control circuitry requires more design circuitry as well as considerable experimentation to ensure existing accessories can be used and that other must criteria are met; b) requires the same experimentation while; c) requires little or none.

6 Shape of Pattern

Patterns make the colour more distinguishable at short range.

7 Uniformity

Patterns will be partially symmetrical but not uniform. Uniformity is further reduced as the number of patterns increases. Failure recognition is easier with uniform patterns.

8 Information of Pattern

Other than the colour, information is increased by the number of patterns.

10 **Maximize Beamwidth**

Beamwidth is compromised if more than one pattern is used for each color. If only one pattern is used some colours will be narrow and some will not.

TYPE I - MECHANICAL

decision statement GIVEN THE POWER REQUIREMENTS + NUMBER OF LED's, CHOOSE THE PACKING WHICH CAN OPTICALLY BE BEST UTILIZED

objectives whatever I choose should:		alternatives a Close pack as many as possible			b Deflange existing and close pack		
must		info	go/no		info	go/no	
1 Range of 1320' Feet			✓			✓	
13 Use of Existing Accessories		easy	✓		easy	✓	
17 Reliability (20 yr. life)			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	good LED density	3	15	27% smaller area optimum density	6	30
1b Range of 2500 feet	9	good LED density	4	36	27% smaller area optimum density	6	54
3 ~~Minimize Power~~ Consumption	6	fewer LED's	4	24	max. number of LED's	3	18
4 Minimize Cost	5	fewer LED's	3	15	max. number of LED's	2	10
5 Manufacturability	7	small lens	5	35	~~deflanging required~~ smaller lens	4	28
9 Maintainability	8	poor access to LED	2	16	difficult to access	1	8
10 Maximize Beamwidth	3	narrower beamwidth	4	12	best beamwidth	5	15
				153			163

alternatives								
c Use Fewer Less Closely Packed			d Close Pack Some and not others			e		
info	go/no		info	go/no		info	go/no	
Number of LED's in optically acceptable area reduces range	no go			✓				
More Difficult	✓		Most Difficult	✓				
	✓			✓				
info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
			poor density	2	10			
			poor density	3	27			
			minimum LED's	4	24			
			minimum LED's	3	15			
			difficult to access some	1	8			
			narrower beamwidth	4	12			
			large lens	4	28			
					124			

TYPE I - MECHANICAL - GIVEN THE POWER REQUIREMENTS AND NUMBER OF LED's, CHOOSE THE PACKING

1 Range of 5000 Feet

Of importance here is the number of LED's, area of the array and the beamwidth of the LED's. If the number of LED's is fixed then the packing will determine the area of the array. The area of the array partially determines its position relative to the existing lens. This in turn along with the half intensity angle of the LED's determines the beam width of the signal. To compensate for the above effects the number of LED's and therefore area can be reduced, however, this reduces the intensity. There are also mechanical restrictions to how close to the existing lens the array could go but these are minor.

1b Range of 2500 Feet

The same criterion as are used for 1a apply here with the score indicating the ability to meet the 2500 foot range requirement only.

3 Minimize Power Consumption

This is directly proportional to the number of LED's used.

4 Minimize Cost

This is related both to the number of LED's and their density.

5 Manufacturability

The denser the packing the more machining required (i.e., deflanging). Also alignment may be more difficult. Lens manufacture becomes easier with smaller size.

9 Maintainability

The ease of access to failing components is made more difficult with closer packing.

10 Maximize Beamwidth

This is optimized for the closes packing of LED's.

TYPE I - MECHANICAL

decision statement: TO CHOOSE THE BEST ALIGNMENT METHOD GIVEN THE PACKING AS CLOSE PACK DEFLANGE NUMBER OF LED's WITH QUALIFICATION FOR MINIMUM ALIGNMENT

objectives whatever I choose should:		alternatives a PCB lead (singly tuned)			b Alignment overlay		
must		info	go/no		info	go/no	
5 Minimum beamwidth of ±2°			✓			✓	
11 Withstand shock, vibration etc. as expected			✓			✓	
14 Maintenance period of at least one year			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	acceptable	3	15	best	5	25
1b Range of 2500 feet	9	acceptable	4	36	best	6	54
4 Minimize Cost	5	OK	5	25	mold required	2	10
5 Manufacturability	7	Easy	5	35	more difficult	4	28
9 Maintainability	8	OK	3	24	best	4	32
10 Maximize Beamwidth	3	OK	3	9	OK	3	9
				144			158

alternatives								
c Body References			d			e		
info	go/no		info	go/no		info	go/no	
	✓							
	✓							
	✓							
info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
acceptable	4	29						
acceptable	5	45						
better tolerance required	3	15						
easy	5	35						
OK	3	24						
OK	3	9						
	157							

TYPE I - MECHANICAL - TO CHOOSE THE BEST ALIGNMENT METHOD GIVEN THE PACKING AND NUMBER OF LED's

1a Range of 5000 Feet

A force fit focus using an overlay should give the best range though LED's leads body reference should be acceptable with body reference being slightly superior.

1b Range of 2500 Feet

The same criterion used for 1a apply here with a range of 2500 feet applying only.

4 Minimize Cost

An alignment overlay requires a mold and is therefore the most expensive. The body reference method requires closer tolerances in LED deflanging and lead hole spacing on the PCB.

5 Manufacturability

An alignment overlay requires an additional step in manufacture. The other two do not.

9 Maintainability

An alignment overlay allows realignment should it be necessary. Body reference and lead alignment require more work to realign.

10 Maximize Beamwidth

All should be comparatively the same.

RECOMMENDATIONS

a) Exact Form of Prototypes

The prototype will consist of an array of about 200 LED's deflanged and arranged in a hexagonal close-packed uniform pattern of three colours. The LED's will be aligned by their leads in the printed circuit board. The LED's used will be DR1 Red, DG2 Green and DY1 Yellow.

The optics will consist of a plano-concave lens ground from plastic or glass depending on availability. The lens will have a diameter of 88 mm, a focal length of 116 mm and a radius of curvature of 60 mm.

The mechanical support for the smart box, printed circuit board and lens will be similar to those designed in Phase I of the project with slight modifications for adjustment and alignment.

b) Configurations to Build

1 - Uniform array of 121 LED's, 42 Red, 42 Yellow, 37 Green

1 - Non-uniform array of 121 LED's using fewest possible DR1 reds and appropriate number of yellows and greens to give reliable signal aspect identification at a range of 500 m.

4 - N-U arrays of 199 LED's using DR2 reds giving range of 900 m.

1 - N-U experimental array of 199 or more LED's a range of 5000 ft. for all three colors.

TYPE I - COSTING (Revised 04/03/85)

Disbursements

		Qty/unit	# units	$/ea.	Subtotals
1)	Lens	1 x	6	x 150	$ 900.00
	Tooling & Setup		1	400	400.00
2)	LED's - DR2	68	6	2.50	1,020.00
	- DY1	68	6	.83	338.00
	- DG1	68	6	1.12	460.00
3)	Resistors	200	6	.06	72.00
	Components	1 set	6	25	150.00
4)	PCB	1	6	185	1,110.00
		PCB + Lens Subtotal			$4,450.00
5)	US + S Mechanical Packaging & Assembly		6	1606	9,636.00
		Mechanical Subtotal			$ 9,636.00
TYPE I - Total Disbursements (without Electronics)					$14,086.00
	Labour - Procurement			$400	400.00
	Assembly -		6 units @	300	1,800.00
	Debug, Test, Characterize		6 @	600	3,600.00
	Documentation			2,000	2,000.00
Labour Subtotal					$ 7,800.00
TOTAL COST	Disbursements				$14,086.00
	Labour				$ 7,800.00
					$21,886.00

Decision Statement: SELECT THE OPTIMUM 'SMART BOX' DESIGN

Establish and Classify Objectives:
List the important results to be accomplished, resources to be used, and limits to be observed in this decision

Objectives	Relative Importance	Objectives	Relative Importance
ENVIRONMENTAL:	10	FAILSAFE OPERATION:	10
- Thermal: -40 to +80°C Storage, High Humidity: -40 to +70°C Working		- Colour failure to more Restrictive	
- Vibration Survival: 5 g max, 25 hrs @ 400 hz & 25 hrs @ 25 hz	10	REDUNCANCY:	8
- Transient Survival: 10 surges from a source leading edge of 100 kHz & exp.	10	- LED failure - reduced luminance not total failure	
decay @ 50 kHz		INDICATION OUPTUTS: - 60 mA @ 12 v	10
POWER SUPPLY: - Consumption _ 18 Watts	10	OPERATION: - Compatible control signals	10
- Operating Voltage: 8 - 15 V ac or dc	10	RELIABILITY: - no moving parts	10
MATERIALS AND WORKMANSHIP:	9	- minimum parts count	9
- Conformance to AAR Signal Specs., Parts 84, 93, 119, 136, 186, 275, 282		COST: minimum - initial material & assembly	4
LIFESPAN: - 220 years continuous service	9	- repairs & maintenance	8
- scheduled maintenance interval 1 yr. etc. as expected in railway environment	10		

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ELECTRONIC SMART BOX

decision statement WHERE SHOULD THE INDICATION OUTPUTS BE SENSED?

objectives whatever I choose should:		alternatives					
		a Mirror the Control Signal			b Sense LED Current		
must		info	go/no		info	go/no	
Be Failsafe		light should always be at least as restrictive	✓		No Current = No Light	✓	
Have Compatible Outputs			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
Max Reliability	10		5	50		4	40
Min. Cost	5		4	20		3	15
Light Out Indication	8		2	16		4	32
				86			87

ELECTRONIC SMART BOX

decision statement IS IT WORTHWHILE INTERNALLY MONITORING LIGHT OUTPUT

objectives whatever I choose should:		alternatives a Light Sense Feedback			b Open Loop Control		
must		info	go/no		info	go/no	
Meet Environmental Specs			✓		No Current = No Light	✓	
Have Compatible Outputs			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
Max Reliability (Minimum Parts)	9		2	18		5	45
Lowest Number of Non-Failsafe Failure Modes	10		5	50		4	40
Lowest Cost	5		2	10		5	25
Minimum Power Usage	4		4	16		5	20
				94			130

alternatives								
c Sense LED Light			d			e		
info	go/no		info	go/no		info	go/no	
direct monitoring	✓							
	✓							
info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
	1	10						
	2	10						
	6	48						
		68						

ELECTRONIC SMART BOX

decision statement SHOULD THE INDICATION OUTPUTS BE RELAY OR SOLID-STATE

objectives whatever I choose should:	alternatives					
	a Solid-State Outputs			b Relay Indication Outputs		
must	info	go/no		info	go/no	
Meet Environmental Specs		✓			✓	
Have No Moving Parts		✓			no go	
Be Compatible with Existing Equipment		✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.

ELECTRONIC SMART BOX

decision statement SHOULD LED DRIVE CIRCUIT UTILIZE A DC-DC CONVERTER (TO PROVIDE A REGULATED HIGH VOLTAGE)

objectives whatever I choose should:		alternatives					
		a DC-DC Converter			b Low Voltage Regulator		
must		info	go/no		info	go/no	
Operate on 8-15 Vac or dc at less than 18 Watts			✓			✓	
Meet Environmental Specifications			✓			✓	
Be Compatible with Existing Equipment							
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
Survival of 10% LED failure	8		6	48		6	48
No moving parts	10		6	60		6	60
Minimum parts count	9		5	45		4	36
20 Year continuous life	9		4	36		5	45
Scheduled Maintenance Interval 1 year	10		6	60		6	60
Min. Maintenance Cost	8		3	24		4	24
Min. Capital Cost	4		3	12		4	16
Min. Power Usage	7		4	28		3	21
				313			310

SMART BOX DESIGN GUIDELINES

Based on the preliminary decision analysis the following circuit design guidelines are recommended:

a) the indication outputs should be derived from sensing the LED current.

b) the indication outputs should use solid state devices instead of relay outputs.

c) the LED array should be powered by a DC-DC converter.

d) internal monitoring of the light is not recommended.

AREAS OF MATRIX EVALUATION - TYPE II

The various alternatives have been grouped into three main categories: LED's, Optics and Mechanical. These are further divided as shown below:

MAIN CATEGORY	SUB CATEGORY	ALTERNATIVE
LED's	Red	DR2, DR1, DR3
	Green	DG1, DG2, Green with blue, Wait for correct chromaticity
	Yellow	DY1, DY2, DY3, DY4, Wait for correct chromaticity
Optics	Type	Ellipsoidal, spherical
	Ellipsoidal	Molded LED, Flat LED glued on lens, ground lens, molded lens
	Material	Glass, Plastic
	Shape	Round, Square, Hexagonal
	Patterns	Different pattern for same color different meaning, One pattern per color maximized for recognition of pattern, Pattern for luminance maximized and uniformity
	Hot Spots	Separate Array, Existing accessories, new accessories
Mechanical	Packing	Closepack, use fewer less closely packed, close pack some and not others
	Alignment	PC load, alignment overlay, body reference

Decision Statement: TO CHOOSE THE OPTIMUM TYPE II ARRAY PROTOTYPE

Establish and Classify Objectives:
List the important results to be accomplished, resources to be used, and limits to be observed in this decision

	Objectives	Relative Importance		Objectives	Relative Importance
1	Minimum Range of 1320 feet	10	13	Suppression of phantom Aspects	10
2	Three required colours	10	14	Maintenance of at least one year	10
3	No moving parts		15	One lens per LED or no lens for more than one LED	10
4	Fit existing mounting	10	16	Reliability (20 yr. life span)	
5	Minimum Beamwidth of ±2°	10			
6	Light emitting surface comparable	10			
7	Redundant configuration of each colour	10			
8	Power consumption _ 18 Watts	10			
9	Materials & Workmanship to AAR Specifications	10			
10	Operate over -40°C to 70°C normally	10			
11	Withstand shock, vibration & humidity etc. as expected in railway environment	10			
12	Include beam spreading, deflecting and hot spot accessories	10			

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OBJECTIVES

Main

The main objectives are based on the design guidelines and the work statement for prototype development.

Want

These are based on the design guidelines, work statement for prototype development and the CN searchlight specification and design recommendations. They are clarified below.

1a Range of 5000 feet

This would allow complete interchangeability of Type II prototypes and existing searchlight. The requirement for 1320 feet is a minimum with 5000 feet as a desirable upper limit. The main criterion here is that the array be visible at 5000 feet.

1b Range of 2500 Feet

This would allow interchangeability of Type II prototypes and existing searchlights in certain applications. The requirement for 1320 feet is a minimum with 2500 as a desirable upper limit. The main criterion is that the array be visible at 2500 feet.

2a Correct Chromaticities

The AAR specifications for the chromaticity should be met if possible. There are not yet available LED's of sufficient intensity to realistically meet these requirements. The development of prototypes however can incorporate LED's of the correct chromaticity when they become available provided they have similar electrical characteristics.

2b Color Distinguishability

There should not be confusion of colors, i.e., yellow for green and green for yellow. This is related to the chromaticity of the LED but also to the intensities and/or relative intensity of each color.

3 Minimize Power Consumption

Since provision of site power is costly, the maximum power consumption of 18 watts is a limit and a lower value is desirable.

4 Minimize Cost

Cost here includes material costs, assembly costs and the capital costs such as special tools, moulds, etc. The expected cost of manufacture of the prototype should be as low as possible.

5 Manufacturability

Since these prototypes are intended eventually to be a production item they should meet requirements of repeatability, manufacturing tolerances at minimum cost, Considerations here are the cost of machining, cost for reproducibility and the cost of specially manufactured parts such as lenses.

7 Shape of Pattern

The pattern shape should be such that it does not cause confusion. The main criterion here is distinguishability of colours.

8 Uniformity of Pattern

This allows ease of failure recognition and also gives better optical characteristics when uniform.

9 Information of Pattern

One colour could convey more than the usual information through pattern changes or low frequency modulation.

10 Maintainability

Once built and tested there should be ease of access to failing components, ease of replacement, in field testing capability and in field focussing and alignment.

11 Maximize Beamwidth

A wider beamwidth allows the light to be seen over a wider angle (eg. curves).

12 Use of Existing Accessories including 8 3/8" Diameter Beam Spreader

This would make this searchlight more interchangeable with parts of existing lights.

13 Mean Time between Failures greater than One Year

A long service life is desirable and of importance is predictably of failure and the degree of failure.

14 Separate LED's for each required color

It is undesirable to have color mixing since confusion of colors can result should failures occur. Also the color mixing is only effective over certain ranges. Close to the light the mixed colrs become visibly seperable.

15 Complete the prototype stage by June 1985

It is desirable to complete the prototype stage so that field testing can begin. This is a target date only.

Decision Statement: TO CHOOSE THE OPTIMUM TYPE II ARRAY PROTOTYPE

Establish and Classify Objectives:
List the important results to be accomplished, resources to be used, and limits to be observed in this decision

Objectives	Relative Importance	Objectives	Relative Importance
1a Minimum Range of 5000 feet	5	12 Mean Time between Failures greater than one year	9
1b Range of 2500 feet	9	13 Use existing accessories including 8 3/8" hem spreader	3
2a Correct Chromaticities	9	14 Seperate LED's for each required colour	7
2b Color distinguishability	9	15 Complete the prototype stage by June 1985	7
3 Minimize power consumption	6		
4 Minimize cost	5		
5 Manufacturability	7		
6 Shape of Pattern	3		
7 Uniformity of Pattern	5		
8 Information of Pattern	2		
9 Maintainability	8		
10 Maximize beamwidth	3		

039

TYPE II - LED's

decision statement TO CHOOSE THE BEST LED's (COLOUR RED)

objectives whatever I choose should:		alternatives a DR1			b DR2		
must		info		go/no	info		go/no
1 Range of 1320'				✓			✓
16 Reliability (20 yr. life span)				✓			✓
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	2000 mcd, 12°	5	25	500 mcd, 12°	3	15
1b Range of 2500 feet	9	2000mcd, 12°	6	54	500 mcd, 12°	5	45
2a Correct Chromaticities	9	within AAR specs	6	54	within AAR specs	6	54
2b Color distinguishability	9	clearly red	6	54	clearly red	6	54
4 Minimize Cost	5	approx. 12.50 each	3	15	approx. 1.00	5	25
10 Maximize Beamwidth	3	12° beamwidth	3	9	12° beamwidth	3	9
15 Complete the prototype by June 1985	7	possible	6	42	possible	6	42
				253			244

alternatives								
c DR3			d			e		
info	go/no		info	go/no		info	go/no	
	✓							
	✓							
info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
5000 mcd, 12°	6	30						
5000 mcd, 12°	6	54						
within AAR specs	6	54						
clearly red	6	54						
approx. 50 each	0	0						
approx. 12° beamwidth	3	9						
not available	0	0						
	201							

TYPE II - LED's

decision statement TO CHOOSE THE BEST LED's (COLOUR YELLOW)

objectives whatever I choose should:		alternatives a DY1			b DY2		
must		info	go/no		info	go/no	
1 Range of 1320'			✓			✓	
17 Reliability (20 yr. life span)			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	140 mcd, 24°	2	10	approx. 125 mcd, 24°	1	5
1b Range of 2500 feet	9	140 mcd, 24°	3	27	approx. 125 mcd, 24°	2	18
2a Correct Chromaticities	9	583 nm	4	36	approx. 580 nm	3	27
2b Colour Distinguish-ability	9	fair to good	4	36	fair	3	27
4 Minimize Cost	5	approx. .70 each	6	30	approx. 1.00 each	5	25
10 Maximize Beamwidth	3	24° beamwidth	5	15	24° beamwidth	5	15
15 Complete by June 1985	7	possible	6	42	possible	6	42
				196			159

alternatives								
c Wait for Correct Chrometicity			d DY3			e DY4		
info	go/no		info	go/no		info	go/no	
	✓							
	✓							
info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
< 140 mcd, 24°	1	5	350 mcd, 24°	3	15	500 mcd, 12°	4	20
< 140 mcd, 24°	2	18	350 mcd, 24°	4	36	500 mcd, 12°	5	45
within AAR specs	6	54	570 nm	2	18	unknown	3	27
clearly yellow	6	54	fair	2	18	fair	5	45
expensive	3	15	approx. $1.00	5	25	expensive	2	10
approx. 24° beamwidth	0	0	24° Beamwidth	5	15	approx. 12° beamwidth	3	9
unavailable	0	0	possible	6	42		0	0
		161			169			156

TYPE II - LED's

decision statement TO CHOOSE THE BEST LED's (COLOUR GREEN)

objectives whatever I choose should:		alternatives a DG1			b Wait for Correct Chromaticity		
must		info	go/no		info	go/no	
1 Range of 1320'			✓			✓	
16 Reliability (20 yr. life span)			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	200 mcd, 24°	2	10	≤ 200 mcd	0	0
1b Range of 2500 feet	9	200 mcd, 24°	3	27	≤ 200 mcd	0	0
2a Correct Chromaticities	9	555 nm	1	9	within AAR specs	6	54
2b Colour distinguish-ability	9	poor	2	18	clearly green	5	45
4 Minimize Cost	5	$1.38	5	25	expensive	2	10
10 Maximize Beamwidth	3	24° beamwidth	5	15	not ensured	3	9
15 Complete by June 1985	7	possible	6	42	not yet available	0	0
				146			118

alternatives

c DG2			d DG1 with blue			e		
info	go/no		info	go/no		info	go/no	
info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
200 mcd, approx 12°	3	15	Blue are approx. 5 mcd	1	5			
200 mcd, approx 12°	4	36	Blue are approx 5 mcd	2	18			
not in AAR spec	1	9	better than avg.	3	27			
poor	2	18	better	2	18			
approx. 1.5	5	25	expensive	1	5			
12°	6	18	unknown	3	1			
not yet available	0	0	not yet available	0	0			
	121			82				

TYPE II - LED's - TO CHOOSE THE BEST LED's

1a Range of 5000 Feet

Intensity of the LED (given in millicandlas) is the main consideration here. Also important is the half intensity angle of the LED and to a lesser degree the chromaticity of the LED. Obviously greater intensity means greater range. The half intensity angle relates to the amount of light in a given area. A narrower beam means greater range. The eye also sees lights of the same absolute intensity differently for different colors. This is particularly true of green in this case.

1b Range of 2500 Feet

The same criterion as are used for 1a apply here with the score indicating the ability to reach the 2500 foot range only.

2a Correct Chromaticities

The AAR specifications for chromaticity were used.

6 was given if these specifications were met.

5 to 1 were given for progressively greater distances from these specifications within the general colour character.

2b Color Distinguishability

The chromaticity of the LED's is important here and green is furthest from the AAR specifications. Also important is the relative intensities of the three colors.

4 Minimize Cost

In this case LED's were rated 6 for less than $.80 for production quantities, 5 for $.80 to $3.00, 4 for $3.00 to $12.00, 3 for $12.00 to $50.00, 2 for $50.00 to $200.00 and 1 for $200.00 and up.

11 Maximize Beamwidth

The greater the half intensity angle of the LED the greater the signal beamwidth.

15 Complete by June 1984

Waiting for LED's of the correct chromaticity or intensity will not allow this criterion to be met.

TYPE II - OPTICS

decision statement TO CHOOSE THE BEST TYPE OF LENS

objectives whatever I choose should:		alternatives a Ellipsoidal (a)			b Spherical		
must		info	go/no		info	go/no	
4 Minimum Beamwidth of ±2°			✓			✓	
5 Light Emitting Surface Comparable			✓			✓	
13 Suppression of Phantom Aspects			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	more collimated	3	24	more losses at edges	2	16
1b Range of 2500 feet	9	more collimated	4	36	more losses at edges	3	27
4 Minimize Cost	5	more costly	2	10	expensive but least costly	3	15
6 Shape of Pattern	2	OK	3	9	has aberration	2	6
7 Uniformity of Pattern	4	OK	3	15	has aberration	2	10
8 Information of Pattern	1	OK	3	6	has aberration	2	4
9 Maintainability	8	acceptable	3	24	acceptable	3	24
13 Use existing accessories	3	acceptable	3	9	acceptable	3	9
10 Maximize beamwidth	3	more collimated	3	3	wider beamwidth	4	4
				136			115

TYPE II - LED's - CHOOSE THE BEST TYPE OF LENS

1a Range of 5000 Feet

The elliptical lens will collimate more LED light into the desired 4° beam producing a more intense beam, achieving a longer range. The spherical lens would lose more light at the edges of the lens.

1b Range of 2500 Feet

The same criterion as are used for 1a apply here with the score indicating the ability to meet the 2500 foot range requirement only.

4 Minimize Cost

The elliptical lens would require custom tooling and would be more expensive as well as more difficult to produce.

6 Shape of Pattern

The spherical lens could cause distortion in the pattern because of its poorer collimation.

7 Uniformity of Pattern

Same as above.

8 Information of Pattern

Same as above.

9 Maintainability

Neither Ellipsoidal or spherical lenses should require much if any maintenance.

10 Maximize Beamwidth

The spherical lens would produce a more dispersed beam and greater beamwidth.

13 Use Existing Accessories

Neither ellipsoidal or spherical lenses should require the use of completely new accessories.

TYPE II - OPTICS

decision statement TO CHOOSE THE BEST ELLIPSOIDAL LENS

objectives whatever I choose should:		alternatives a Molded LED			b Flat LED glued or LENS		
must		info	go/no		info	go/no	
5 Minimum Beamwidth ±2°			✓			✓	
15 One lens per LED			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	most concentrated beam	5	15	poor attachment	2	10
1b Range of 2500 feet	9	most concentrated beam	6	54	poor attachment	3	27
4 Minimize Cost	5	expensive	2	10	expensive	2	10
6 Shape of Pattern	2	too intense	1	2	poor - light less	2	4
7 Uniformity of Pattern	4	beam too narrow	1	4	poor on LED edge	2	8
8 Information of Pattern	1	beam too narrow	7	7	poor	2	2
9 Maintainability	8	OK	3	24	difficult	2	16
13 Use existing accessories	3	OK	3	9	OK	3	9
10 Maximize beamwidth	3	beam too narrow	0	0	poor beam	2	6
				125			92

alternatives								
c Ground Lens			d Molded Lens			e		
info	go/no		info	go/no		info	go/no	
	✓			✓				
	✓			✓				
info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
good collimation	4	20	acceptable	3	15			
good collimation	5	45	acceptable	4	36			
cheap	4	20	OK	3	15			
good	4	8	OK	3	6			
good	4	16	OK	3	12			
OK	3	3	OK	3	3			
OK	3	24	OK	3	24			
OK	3	9	OK	3	9			
OK	3	9	OK	3	9			
		154			129			

TYPE II - OPTICS - TO CHOOSE THE BEST ELLIPSOIDAL LENS

1a Range at 5000 Feet

A molded LED would give the best possible collimation and the most concentrated beam, hence best range. The ground lens would be superior to the molded lens which would be prone to defects and not as sharp in image quality. The flat LED would lose light at the join because of difficult alignment and machining of the LED.

1b Range of 2500 Feet

The same criterion as are used for 1a apply here with the score indicating the ability to meet the 2500 foot range requirement only.

4 Minimize Cost

The molded LED and the flat LED are the most expensive as customized and difficult machining of the LED's would be required. A molded lens would be cheapest in large scale production but would be more expensive than the non-molded lens for prototype production.

6 Shape and Uniformity of Pattern

The molded LED would produce a high intensity point of light which would be difficult to use in producing a pattern. The flat LED could have light leakage at the join which would make patterning difficult. The not-molded lens would give a sharper beam than the molded lens.

7 Uniformity of Pattern

The uniformity of the pattern is dependent on the narrowness of each individual LED-lense combination as well as the ease of alignment and consistency of alignment.

8 Information of Pattern

Same as above, but the difference between the molded and not-molded lens is negligible for this application.

9 Maintainability

All the combinations would have axial alignment difficulties. The flat LED would have an extra degree of freedom making it the most difficult to align.

10 Maximize Beamwidth

The molded LED would produce the narrowest beam possible.

13 Use Existing Accessories

The use of most existing accessories should be relatively easy. It will depend on the uniformity of the output light and the pattern used.

TYPE 11 - OPTICS

decision statement TO CHOOSE THE BEST TYPE OF LENS MATERIAL

objectives whatever I choose should:		alternatives a Plastic			b Glass		
must		info	go/no		info	go/no	
9 Materials & Workmanship to ARR Specifications							
11 Withstand Shock & " vibrations as expected							
16 Reliability (20 year life span.)							
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 Feet	5	OK	3	15	Clearer	4	20
1b Range of 2500 Feet	9	OK	4	36	Clearer	4	45
4 Minimize Cost	5	Cheap	4	20	OK	3	15
5 Manufacturability	7	Easy	4	28	OK	3	21
7 Uniformity of Pattern	4	OK	3	12	Sharper Image	3	12
				111			113

TYPE II - OPTICS - TO CHOOSE THE BEST LENS MATERIAL

1a Range of 5000 Feet

Glass is a clearer material though both would give acceptable ranges.

1b Range of 2500 Feet

The same criterion as are used for 1a apply here with the score indicating the ability to meet the 2500 foot range requirement only.

4 Minimize Cost

Plastic is a much cheaper material than glass.

5 Manufacturability

Plastic is much easier to work with than glass but glass is still the most commonly used material for lens manufacture.

7 Uniformity of Pattern

Glass provides a much better optical quality image, but it is questionable that this would be visually noticeable.

TYPE II - OPTICS

decision statement TO CHOOSE THE BEST SHAPE FOR ARRAY

objectives whatever I choose should:		alternatives a Round (8 3/8 dia.)			b Square (full area av.)		
must		info	go/no		info	go/no	
1 Range of 1320'			✓			✓	
6 Light emitting surface comparable			✓			✓	
8 Power consumption 18 Watts			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 Feet	5	poorest range	2	10	most LED's	6	30
1b Range of 2500 feet	9	poorest range	3	27	most LED's	6	54
3 Minimize Power	6	least LED's	3	18	most LED's	1	6
4 Minimize Cost	5	least LED's & lenses	4	20	most LED's & lenses	2	10
6 Shape of Pattern	2	most consistent with conventional optics	4	8	most unconventional but still acceptable	3	6
7 Uniformity of Pattern	4	uniform	4	16	OK	4	16
8 Information of Pattern	1	OK	3	3	more possibilities for information content	5	5
10 Maximize beamwidth	3	acceptable	3	9	wider beamwidth but not wider beam angle	4	12
13 Use Existing Accessories Consumption	3	easy	5	15	more difficult	1	3
				126			142

alternatives								
c Hexagonal (full width available)			d			e		
info	go/no		info	go/no		info	go/no	
	✓							
	✓							
	✓							
info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
intermediate range	4	20						
intermediate range	4	45						
moderate # of LED's	2	12						
moderate # of LED's & Lenses	3	15						
nearly round and therfore conventional	4	8						
uniform	4	16						
OK	3	3						
acceptable	3	9						
possible	3	9						
		137						

TYPE II - OPTICS - TO CHOOSE THE BEST SHAPE FOR THE ARRAY

1a Range to 5000 Feet

The range is most affected by the number of LED's and therefore the square array should by far have the greatest range with the hexagonal next.

1b Range of 2500 Feet

The same criterion as are used for 1a apply here with the score indicating the ability to meet the 2500 foot range requirement only.

3 Minimize Power Consumption

The only criterion here is the number of LED's.

4 Minimize Cost

The LED's and particularly the lenses are the major cost here with the size of the printed circuit board also a factor. The square array would be the most costly.

6 Shape of Pattern

At distances of over 3000 feet the eye does not resolve weel enough to distinguish the shape of these arrays. At closer distances the conventional circular light might be preferred.

7 Uniformity of Pattern

In the horizontal plane all the arrays would appear uniform depending on the pattern used. Here the pattern is assumed to be the same in all three cases.

8 Information of Pattern

As a result of its size and shape the square array could by far convey the most information at closer distances. The information at longer distances would be similar.

11 Maximize Beamwidth

The square array being larger would have a larger width of beam though the beam angle would not change since it is a property of the lense - LED combination only.

13 Use Existing Accessories

All three could use the existing accessories but only the round array would make use of all the light available for beam spreading hot spots etc. The hexagonal array would still use most of its light while the square array would use much less.

TYPE II - OPTICS

decision statement TO CHOOSE THE BEST PATTERN GIVEN THE PACKING METHOD

objectives whatever I choose should:		alternatives					
		a Different Patterns Same Order Different Meaning			b One Pattern/Colour max. for Recognition of Pattern		
must		info	go/no		info	go/no	
1 Range of 1320'		possible for Red & possibly green	✓		not relevant at large distances	✓	
7 Redundant Configuration		great care necessary	✓		great care necessary	✓	
12 Include accessories		great cave necessary	✓		great care necessary	✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	some patterns weak	2	10	boosts weak colours	5	25
1b Range of 2500 feet	9	some patterns weak	3	27	boots weak colours	6	54
3 Minimize Power Consumption	6	more control needed	2	12	OK	3	18
4 Minimize Cost	5	more design, circuitry	2	10	OK	3	15
6 Shape of Pattern	2	complicated, inefficient	1	2	improved discrimination	4	8
7 Uniformity of Pattern	4	non-uniform	1	4	poor pattern	3	14
8 Information of Pattern	1	gives colour & information	5	5	indicates colour	1	1
10 Maximize Beamwidth	3	beamwidth compromised	1	3	some colours narrow	3	9
				73			144

alternatives								
c Pattern for Luminance max. + uniformity			d			e		
info	go/no		info	go/no		info	go/no	
	✓							
	✓							
	✓							
info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
optimized average	5	25						
optimized average	6	54						
OK	3	18						
OK	4	20						
uniform shape	3	6						
very uniform	6	24						
no information	1	1						
optimized average	4	12						
		160						

TYPE II - OPTICS - TO CHOOSE THE BEST PATTERN GIVEN THE PACKING METHOD

1a Range of 5000 Feet

The eye can only resolve objects at a ratio of 3000 to 1 objects at a distance that is at 3000 feet the eye cannot resolve any detail smaller than a foot. Therefore patterns will not affect the range at distances greater than 1320 feet and if an attempt is made to do so using a variety of patterns the range will be reduced due to the decrease in intensity.

1b Range of 2500 Feet

The same criterion as are used for 1a apply here with the score indicating the ability to meet the 2500 foot range requirement only.

3 Minimize Power Consumption

This is affected only by the control required to run the array.

4 Minimize Cost

In a) the control circuitry requires more design circuitry as well as considerable experimentation to ensure existing accessories can be used and that other must criteria are met; b) requires the same experimentation while; c) requires little or none.

6 Shape of Pattern

Patterns make the colour more distinguishable at short range.

7 Uniformity

Patterns will be partially symmetrical but not uniform. Uniformity is further reduced as the number of patterns increases. Failure recognition is easier with uniform patterns.

8 Information of Pattern

Other than the colour, information is increased by the number of patterns.

10 Maximize Beamwidth

Beamwidth is compromised if more than one pattern is used for each color. If only one pattern is used some colors will be narrow and some will not.

TYPE II - OPTICS

decision statement TO CHOOSE THE BEST METHOD OF PROVIDING A HOT SPOT

objectives whatever I choose should:		alternatives a Separate Array			b Existing Deflectors etc.		
must		info	go/no		info	go/no	
9 Materials & Workmanship to AAR Specifications			✓			✓	
11 Withstand Shock & Vibration Range of 1320 Feet			✓			✓	
			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 Feet	5	best range	6	30	poorest range	1	5
1b Range of 2500 feet	9	best range	6	54	poorest range	2	18
3 Minimize Power Consumption	6	uses power	2	12	no power use	6	36
4 Minimize Cost	5	expensive	1	5	fairly cheap	5	25
9 Maintainability	8	acceptable	3	24	acceptable	3	24
5 Manufacturability	7	includes lenses	1	7	easy	6	42
13 Use of Existing Accessories	3	does not use	0	0	uses	6	18
				132			168

alternatives								
c New Accessories			d			e		
info	go/no		info	go/no		info	go/no	
	✓							
	✓							
info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
acceptable	3	15						
acceptable	4	36						
no power used	6	36						
expensive in production quantities	2	10						
acceptability	3	24						
difficult	3	21						
does not use	0	0						
	142							

TYPE II - OPTICS - CHOOSE THE BEST METHOD OF PROVIDING A HOT SPOT

1a Range of 5000 Feet

The separate array would have the best range with the use of existing accessories giving the worst range.

1b Range of 2500 Feet

The same criterion as are used for 1a apply here with the score indicating the ability to meet the 2500 foot range only.

3 Minimize Power Consumption

Only the array requires power.

4 Minimize Cost

The LED's and lenses for a separate array would be expensive. New accessories in prototype quantities would be expensive also.

9 Maintainability

None would be more difficult to maintain.

5 Manufacturability

Lenses would have to be manufactured for a separate array and new accessories could be difficult to manufacture in prototype quantities.

13 Use of Existing Accessories

Only the Option b) uses the existing accessories.

TYPE II - MECHANICAL

decision statement GIVEN THE POWER REQUIREMENTS + NUMBER OF LED's, CHOOSE THE PACKING WHICH CAN OPTICALLY BE BEST UTILIZED

objectives whatever I choose should:		alternatives					
		a Close pack as many as possible			b Deflange existing and close pack		
must		info	go/no		info	go/no	
1 Range of 1320' Feet			✓			✓	
16 Reliability (20 yr. life span)			✓			✓	
12 Include Accessories		easy	✓		easy	✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	good LED density	3	15	27% smaller area optimum density	6	30
1b Range of 2500 feet	9	good LED density	4	36	27% smaller area optimum density	6	54
3 Minimize Power Consumption	6	fewer LED's	4	4	max. number of LED's	3	18
4 Minimize Cost	5	fewer LED's	3	15	max. number of LED's	2	10
9 Maintainability	8	poor access to LED	2	16	difficult to access	1	8
10 Maximize Beamwidth	3	narrower beamwidth	4	12	best beamwidth	5	15
5 Manufacturability	7	small lens	5	35	deflanging required smaller lens	4	28
				133			163

alternatives

c Use Fewer Less Closely Packed		d Close Pack Some and not others		e	
info	go/no	info	go/no	info	go/no
Number of LED's in optically acceptable area reduces range	no go		✓		
More Difficult	✓	Most Difficult	✓		
	✓		✓		

info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
			poor density	2	10			
			poor density	3	27			
			minimum LED's	4	24			
			minimum LED's	3	15			
			difficult to access some	1	8			
			narrower beamwidth	4	12			
			large lens	4	28			
					124			

TYPE II - MECHANICAL - GIVEN THE POWER REQUIREMENTS AND NUMBER OF LED's, CHOOSE THE PACKING

1a Range of 5000 Feet

Of importance here is the number of LED's.

1b Range of 2500 Feet

Of importance here is the number of LED's.

3 Minimize Power Consumption

This is directly proportional to the number of LED's used.

4 Minimize Cost

This is related both to the number of LED's and their density.

9 Maintainability

The ease of access to failing components is made more difficult with closer packing.

10 Maximize Beamwidth

This is optimized for the closes packing of LED's.

5 Manufacturability

The denser the packing the more machining required (i.e., deflanging). Also alignment may be more difficult.

TYPE II - MECHANICAL

decision statement: TO CHOOSE THE BEST ALIGNMENT METHOD GIVEN THE PACKING AS CLOSE PACK DEFLANCE NUMBER OF LED's WITH QUALIFICATION FOR MINIMUM ALIGNMENT

objectives whatever I choose should:		alternatives a PCB lead (indiv. aligned)			b Alignment overlay		
must		info	go/no		info	go/no	
4 Minimum beamwidth of ±2°			✓			✓	
14 Maintenance period of at least one year			✓			✓	
17 Reliability (20 yr. life span)			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	acceptable	3	15	best	5	25
1b Range of 2500 feet	9						
4 Minimize Cost	5	OK	5	25	mold required	2	10
5 Manufacturability	7	Easy	5	35	more difficult	4	28
10 Maintainability	8	OK	3	24	best	4	32
11 Maximize Beamwidth	3	OK	3	9	OK	3	9
				161			137

alternatives								
c Body References			d			e		
info	go/no		info	go/no		info	go/no	
	✓							
	✓							
	✓							
info	sc.	wt. sc.	info	sc.	wt. sc.	info	sc.	wt. sc.
acceptable	4	20						
acceptable	5	45						
better tolerance required	3	15						
easy	5	35						
OK	5	35						
OK	3	9						
	159							

TYPE II - MECHANICAL - TO CHOOSE THE BEST ALIGNMENT METHOD GIVEN THE PACKING AND NUMBER OF LED's

1a Range of 5000 Feet

A force fit focus using an overlay should give the best range though LED's leads body reference should be acceptable with body reference being slightly superior.

1b Range of 2500 Feet

The same criterion as are used in 1a apply with the ability to meet the 2500 foot range only.

4 Minimize Cost

An alignment overlay requires a mold and is therefore the most expensive. The body reference method requires closer tolerances in LED deflanging and lead hole spacing on the PCB.

5 Manufacturability

An alignment overlay requires an additional step in manufacture. The other two do not.

9 Maintainability

An alignment overlay allows realignment should it be necessary. Body reference and lead alignment require more work to realign.

10 Maximize Beamwidth

All should be comparatively the same.

TYPE II - RECOMMENDATIONS

a) Exact Form of Prototypes

The prototype should consist of an array of about 200 LED's arranged in a hexagonal close-packed square uniform pattern of three colours. The LED's will be aligned by their body leads in the printed circuit board. The LED's used will be DR1 Red, DG1 Green and DY1 Yellow. The LED's each will fit in a custom made ellipsoidal lens made of plastic. These lenses should be aligned by body reference in combination with their individual LED's alignment. The existing hot spot accessories should be used if possible.

These recommendations are not as firmly based in experimentation from Phase I of the project as are those for Type I. Thus some changes should be expected as the first prototype is built and tested.

c) Predicted cost of each follows.

TYPE II - COSTING

Disbursements

		Qty/unit	# units	$/ea.	Subtotals
1)	Lens Fabrication	200	10	25	$50,000.00
2)	Mech. - Lens Holders	1	10	1680	16,800.00
	- LED Support Plate	1	10	840	8,400.00
	- Mounting Brackets	1	10	210	2,100.00
	- Box	1	10	450	4,500.00
	- Misc. Comp.	1 set	10	150	1,500.00
3)	LED's - DR1	68	10	12.50	8,500.00
	- DY1	68	10	.83	564.40
	- DG1	68	10	1.12	761.60
4)	Resistors	200	10	.06	120.00
	Misc. Components	1 set	10	25	250.00
5)	PCB - Setup + Photos		1	200	200.00
	PCB	1	10	200	2,000.00
	Disbursements Subtotal (without electronics)				$95,596.00

Labour

Detailed Lense Design	10	2,000	20,000.00
Electrical Assembly	10	350	3,500.00
Mechanical Assembly	10	418	4,180.00
Mech. Design and Drawing			9,680.00
Electrical Testing & Debug	10	150	1,500.00
Optical Testing & Characterization	10	500	5,000.00
Procurement		400	400.00
PCB Design		2,000	2,000.00
Documentation		2,000	$ 2,000.00
Labour Subtotal			$48,260.00

Total Cost

Labour	48,260.00
Disbursements	$95,696.00
Total	$143,956.00

APPENDIX B

YELLOW LED
SPECIFICATIONS

FEATURES	PART NUMBER	MATERIAL	LENS COLOR	VIEWING ANGLE (TYP.)	LUMINOUS INTENSITY (mcd) MIN.	TYP.	@ I_F (mA)	ELEC. PARA. (Page 5)
TAPERED T-1¾ ULTRA-BRIGHT STRAIGHT LEAD TYPES • Ultra intensity light emission in red, green and yellow. • Excellent performance under ambient light conditions. • Clear devices provide excellent point source. • Solid state reliability	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	ID5240-UY	**GaAsP/GaP**	**Yellow/Clear**	**10°**	**60**	**120**	**20**	**F**
TAPERED T-1¾ WIRE-WRAPPABLE OFFSET LEAD TYPES • Popular T-1¾ tapered lens. • Two choices of red for different current levels. • Sturdy wire-wrappable leads. • Solid state reliability.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE F — GaAsP Material (Yellow)

Absolute Maximum Ratings (Ta = 25°C)

DESCRIPTION	SYMBOL	RATINGS	UNIT
Forward Current	I_F	25	mA
Reverse Voltage	V_R	4	V
Power Dissipation	P_D	70	mW
Operating Temperature	T_{opr}	−20 to +75	°C
Storage Temperature	T_{stg}	−30 to +100	°C

Electrical and Optical Characteristics (Ta = 25°C)

DESCRIPTION	SYMBOL	CONDITION	TYP.	MAX.	UNIT
Forward Voltage	V_F	I_F = 20mA	2.1	2.8	V
Reverse Current	I_R	V_R = 4V		100	μA
Peak Wavelength	λ_p	I_F = 15mA	585		nm
Spectral Line Half Width	$\Delta\lambda$	I_F = 15mA	32		nm

YELLOW LED (20 mA)
Vf=2.1

WAVELENGTH	ENERGY
380 nm	0
390 nm	0
400 nm	0
410 nm	0
420 nm	0
430 nm	.66
440 nm	.69
450 nm	.73
460 nm	.76
470 nm	.79
480 nm	.83
490 nm	.85
500 nm	.88
510 nm	.91
520 nm	3.72
530 nm	7.68
540 nm	32.34
550 nm	150
560 nm	581.4
570 nm	1810.6
580 nm	3805.4
590 nm	5270.4
600 nm	5071
610 nm	3785.6
620 nm	2599
630 nm	1722.7
640 nm	1119.4
650 nm	711.5
660 nm	458.4
670 nm	297.6
680 nm	202.95
690 nm	145
700 nm	102.1

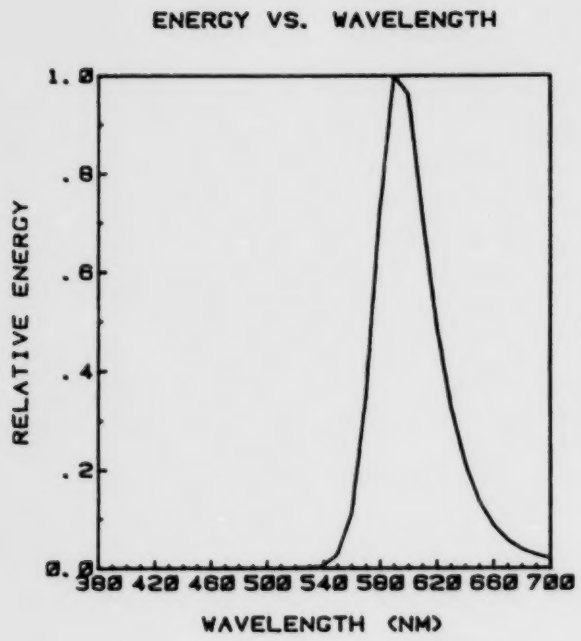
x,y COORDINATES ARE .590, .409

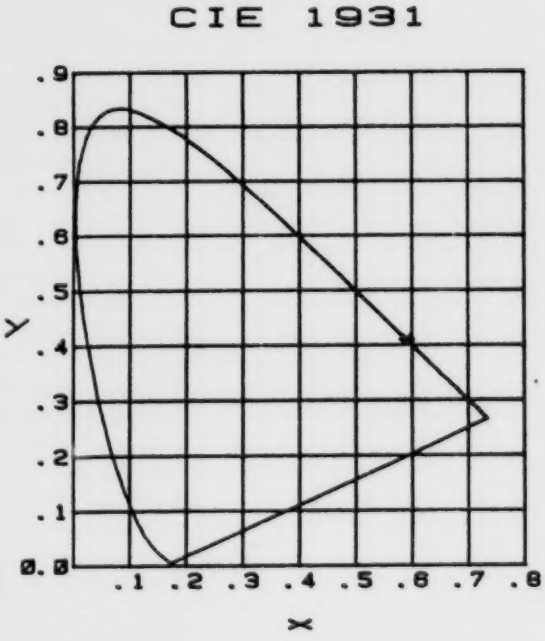
u,v COORDINATES ARE .350, .365

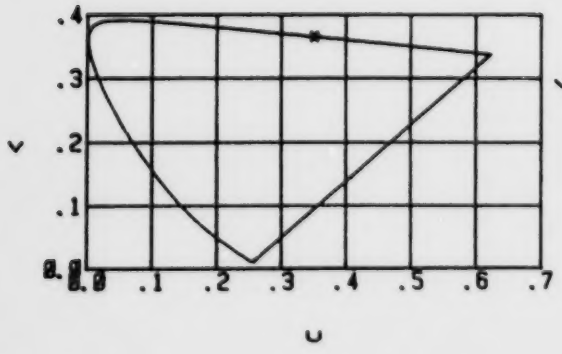
u',v' COORDINATES ARE .350, .547

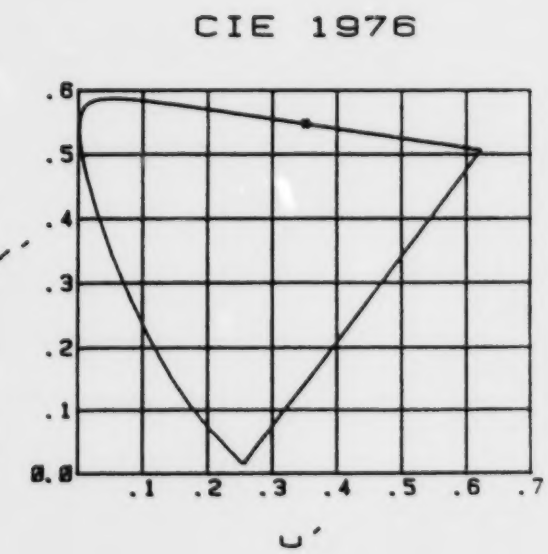
L* = 46.22
a* = 40.92
b* = 96.84

YELLOW LED (20 mA)









YELLOW LED (50 mA)

WAVELENGTH	ENERGY
380 nm	0
390 nm	.94
400 nm	1.06
410 nm	1.16
420 nm	1.24
430 nm	1.32
440 nm	1.38
450 nm	1.46
460 nm	2.28
470 nm	2.37
480 nm	2.49
490 nm	2.55
500 nm	2.64
510 nm	3.64
520 nm	5.58
530 nm	16.32
540 nm	59.78
550 nm	253
560 nm	957.78
570 nm	3047.2
580 nm	6497.8
590 nm	9784.8
600 nm	10087
610 nm	8008
620 nm	5322.3
630 nm	3381
640 nm	2099.6
650 nm	1262.6
660 nm	800.4
670 nm	511.83
680 nm	343.17
690 nm	235
700 nm	165.06

x,y COORDINATES ARE .596, .404

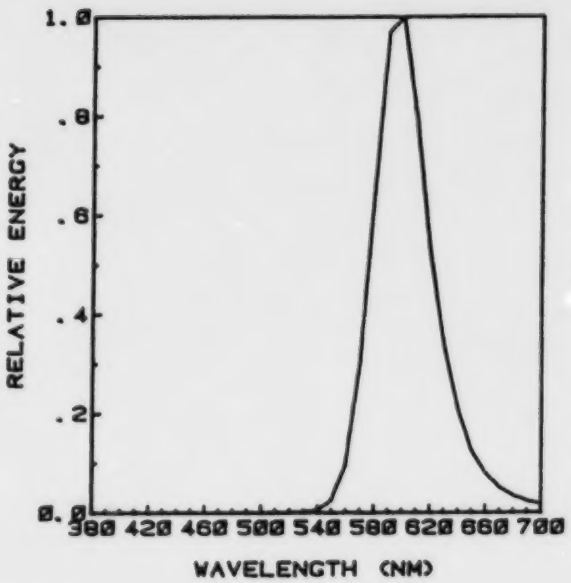
u,v COORDINATES ARE .358, .364

u',v' COORDINATES ARE .358, .546

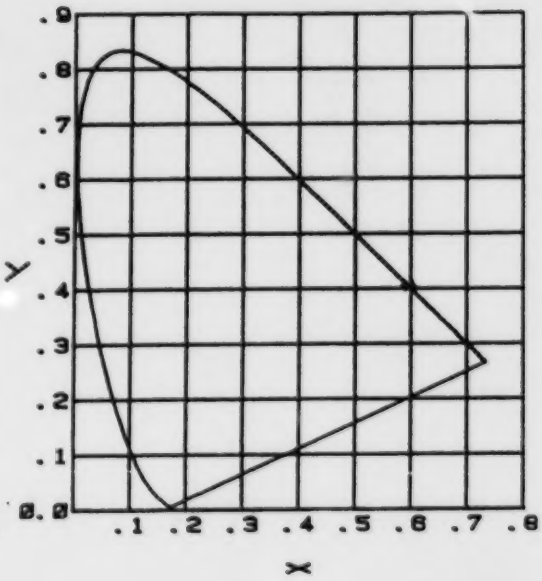
L* = 62.95
a* = 53.35
b* =118.70

YELLOW LED (50 mA)

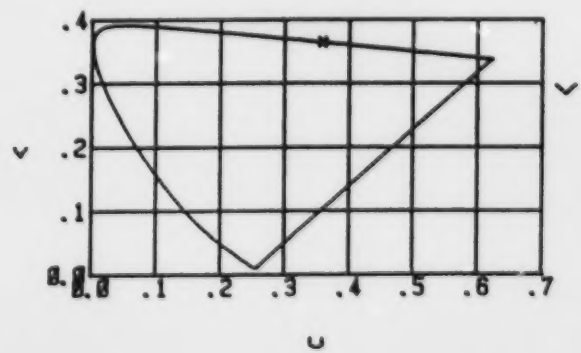
ENERGY VS. WAVELENGTH



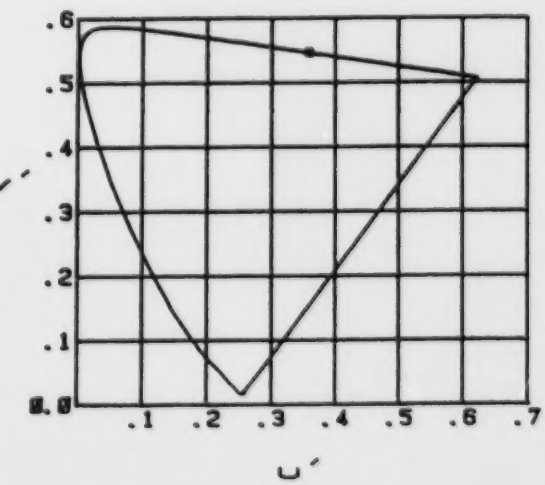
CIE 1931

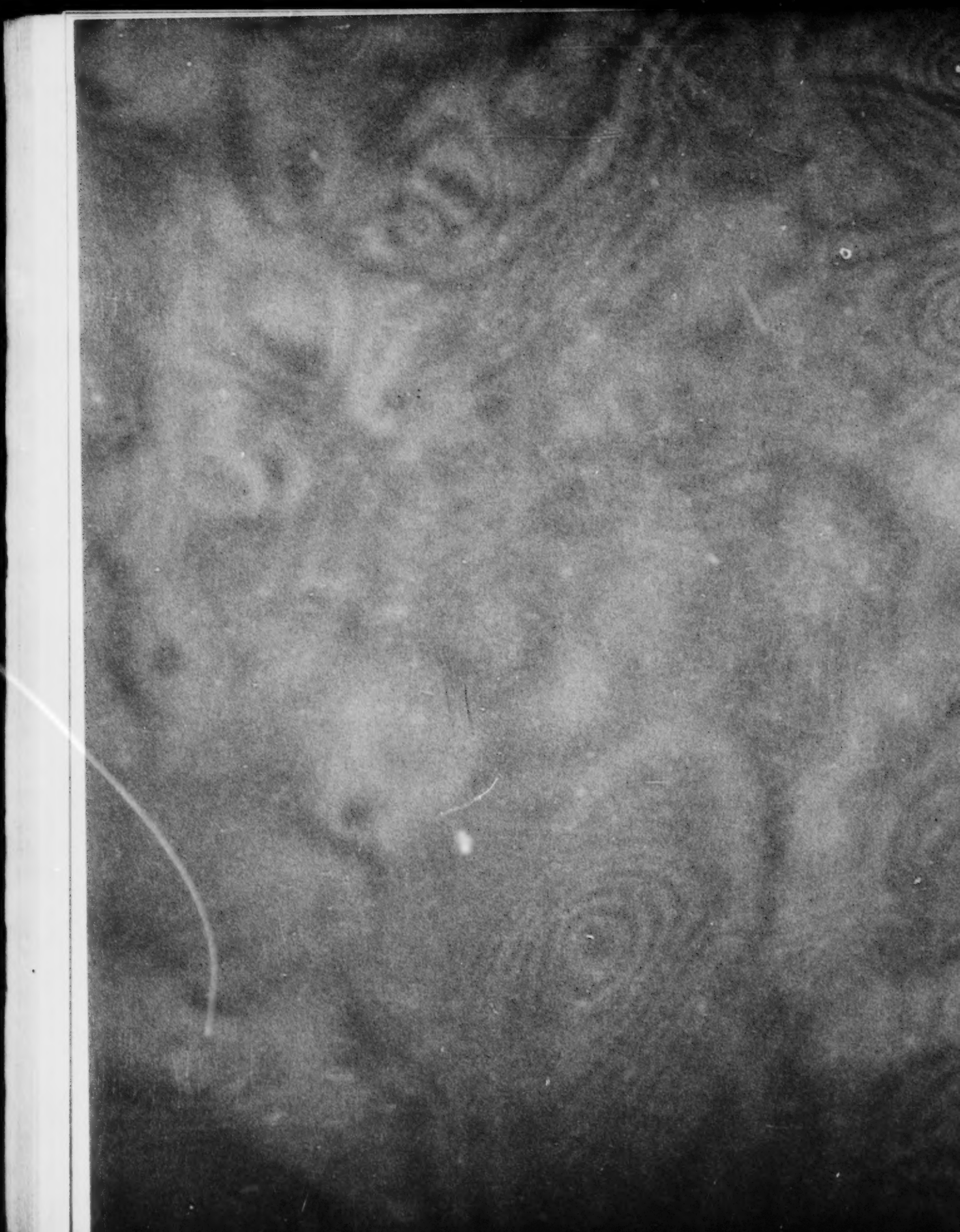


CIE 1960



CIE 1976





APPENDIX C

EXCERPTS FROM
MEETINGS AND RANGE TEST RESULTS

1ST MEETING OF STEERING COMMITTEE
November 8, 1984

Mr. Lougheed stated that a Decision Analysis procedure is being employed by Davis Engineering as an aid to the design process for the prototype signals. An explanation of the procedure was provided by Mr. Wong. He demonstrated the application of the process using the worksheets developed to date for design of the control unit. Hard copies of the transparencies used by Mr. Wong are attached as Annex B. The Decision Analysis procedure will also be used for design of the other components of the signals; i.e., LED array, lens, etc.

Mr. Chapman stated that he would like a preliminary evaluation to be made as soon as possible, of the range of the Type 1 signal. Committee members agreed with the desirability of such an evaluation and there was some discussion as to how it could be done. It was agreed there was no necessity for it to be done on railroad property. Mr. Lougheed will develop the methodology for an outdoor evaluation of the preliminary prototype Type 1 signal developed in Phase 1. The evaluation will be scheduled for somewhere in the Ottawa area. The data will coincide with the next meeting of the Steering Committee.

In response, to a query from Mr. Tansley, Mr. Field stated that the site to be used for outdoor evaluation of the prototype units produced in Phase 2 will be such that the units can be tested for visibility at a distance as great as 5000 ft. The criteria will be only two; viz. ability of the observer to see the lighted signal and to correctly identify the colour being displayed.

The matter of availability of blue LED's was discussed and reference was made to the article from the Oct. 8, 1984, issue of Electronics Week, describing Siemen's process for producing silicon carbide blues. (Copy of referenced article is attached as Annex C).

A lighted pre-production blue silicon carbide type LED was exhibited by Mr. Lougheed. Its brightness was very much lower than LED's of other colours, but lab-produced blue diodes are said to be several times brighter. Cost of the blues is currently said to be $16 to $30 each depending on quality. Mr. Lougheed will attempt to obtain some of the lab-produced blue diodes. Mr. Lougheed advised that the present cost of the DR1 red LED's is around $8 each for quantity purchases.

Mr. Lougheed advised that he has had discussions with an American railway supplier with respect to sharing of the costs that would be incurred to bring the LED signals to the marketing stage, provided evaluation of the prototype proves favourable. Progress in that area is slow, partly because of its concern about the high level of those costs (estimated to be in the order of $1 million), relative to the apparent market for the signals. he also noted that the cost of the lens mold for the prototype Type 2 signal will be in the order of $50,000, and he is exploring possibilities for government funding to assist.

Davis Engineering
Consulting Engineers

December 20, 1984

DE File No: C84-129

Mr. W.G. Rowan
Senior Development Officer
Current Technology Division
Transportation Development Centre
1000 Sherbrooke Street West
P.O. Box 549
Place de l'aviation
Montreal, Quebec
H3A 2R3

Dear Wayne,

Re: Railway Colour Light Signal

In preparation for our next Steering Committee meeting, I have a number of items for your consideration:

1) For preliminary evaluation of the range of the LED signal, I set up a brief test of a Type 1 breadboard unit (number 11, figure 28 of phase I report) at noon on a clear day (sun at zenith). We ran the LED signal alongside a standard searchlight and tried to visually assess range and relative luminance (brightness).

   Results were encouraging, given that this breadboard is far from optimized; range of the red LED is about 1 mile, at apparently ½ the luminance of the conventional signal. Ranges for the yellow and greens were less, approximately ½ mile, and they were visibly less bright, but this breadboard did not favour either. Also, it did not use the super-bright Stanley H2K LEDs (red).

   We also noticed very enhanced visibility due to flickering of the signal (a poor battery connection!), and in line with Dr. Tansley's suggestions it might be useful to explore rapid modulation (eg. 10 times/second, not completely off) as an additional technique.

   The red LED signal was more visible than the regular green signal.

.../2

2nd MEETING OF STEERING COMMITTEE
January 10, 1985

It was concluded by the Committee, that Davis should, at least for the time being, defer making any agreement with any foreign firm that might result in that firm gaining leverage in the market place. Also, it was agreed that:

- The principal immediate thrust of the contractor will be development of the Type I light for "seeability" and colour (chromaticity of Y&G) at maximum possible range and minimum range of 1320 ft., using present LED technology with and/or without modulation.

- Development of the Type 2 light will proceed in parallel but with lower priority than the Type 1.

- CN will serve as a resource to the contractor for the development of the "smart box" insofar as understanding existing signal circuitry is concerned, and the necessary collaboration between CN signal and Davis personnel will commence as quickly as can be arranged.

Following lunch, the Committee moved to a long tangent location on a township road approximately 10 km from the Davis office, for a non-scientific distance observation of the current Type 1 LED configuration relative to a standard US&S searchlight. For this purpose, both lights had been mounted in the back of a panel truck. On arrival at the pre-selected site, the panel truck was parked on the shoulder of the highway, the rear doors opened and the lights focused so that their beams were directed as accurately as possible parallel to the highway. The Committee remained at a distance of almost 500 metres (1600 ft.+) to the rear of the truck, maintaining communication with the personnel in the truck via radio. Following observation from that location, the Committee moved to a location approximately 1800 metres (5900 ft+) from the panel truck for additional observations.

The standard US&S searchlight signal was powered with a 10 volt, 11 watt tungsten lamp operating at approximately 9.7 volts. The LED display was comprised of 42 DR1 red, 42 DY1 yellow and 37 DG1 green. The display was operated at .05 A per LED - i.e., approximately 2 watts total for each colour.

At each location, observations were made of the visibility of the two signals in the steady and flashing modes, and, in the case of the LED signal, also in the modulating mode.

Upon return to the Davis offices, the observations were discussed. It was the concensus that at both 500 and 1800 metres the red LED display was more visible than the US&S signal - in the order of 10 to 20

percent better. The yellow and green LED display were only marginally visible at 500 metres and colour could not be discerned by most of the observers. Flashing at various rates did not appear to improve visibility, but did assist in first picking up the signal with the eye. At 1800 metres, the yellow and green LED displays were not visible to most observers. It was noted by the operators that they did not believe the displays were 100 percent accurately focused parallel to the road.

It was agreed that there needs to be a significant increase in the intensity of both the green and yellow LED display and that additionally, the green needs to be more bluish and the yellow more amber. Inasmuch as the red is much brighter than necessary, it is evident that with present LED technology, a non-uniform array is desirable, i.e., more yellow and more green than reds: however, it seems unlikely that satisfactory visibility of the yellow and green at the specified minimum range of 1320 ft. (approx. 400 metres) can be achieved without increasing the total number of LED's above the 121 used in the test array.

Various suggestions as to the most cost-effective procedure to follow to arrive at the optimum array were discussed. The contractor will consider these, select the best and proceed to that end.

LETTER FROM TRANSPORT CANADA
DATED JANUARY 23, 1985

Further to the item 4 of the minutes, dealing with the "Decision Analysis" report distributed at the meeting, the Committee met January 17th and reviewed it in greater depth and offered the following comments:

1) Type 1 "Must" objectives (pg.9) - Relative importance of item 15 should be 10; Separated LED's exclusively for each colour is not considered essential so importance could be reduced or objective downgraded to "Want" with the same applying to item 17. A marked-up copy of page 9 is enclosed.

2) Relative importance of Type 1 "Want" objectives (pg.12) have been ranked by the committee members and a concensus copy is enclosed.

3) Revised page 13 worksheet choosing the best LED for red colour is enclosed. Although the DR1 wins by a small margin, the use of the alternate, considerably cheaper DR2 in some of the type 1 prototypes would seem desirable since the intensity is close to that of the present yellow and green LED's and a range of 2500 feet might be achieved without increasing the quantity beyond the 42 used in the initial prototype.

4) A decision statement for choosing the number of LED's in the array was missing from the decision analysis report.

5) Recommendations (pg.2)

   a) Use both DR1 and DR2 reds for building prototypes.
   b) Limit number of type 1 arrays to 6 and configurations to 3 or 4 at the most. Conduct some further experimentation to optimize the mix of red, yellow and green in the 199 array. The most desirable prototype configuration for future test purposes are:

      1 - Non-uniform array of 121 LED's using fewest possible DR1 reds and appropriate number of yellows and greens to give reliable signal aspect identification at a range of 500m.

      4 - N-U arrays of 199 LED's using DR2 reds giving range of 900m.

      1 - N-U experimental array of 199 or more LED's a range of 1600 m for all three colours.

6) Costing (pg.33)

Change the line extensions based on a quantity of 6 units which will reflect an overall reduction of about $15,000.

7) Committee will defer comments on "smart box" design as a result of decision for CN-Davis meeting and lower priority classification.

8) Ranking of relative important of "WANT" objectives for Type II (pg.45) should reflect the same order as type I (pg.12).

9) Agree with recommended form of prototype (pg.67) except for substitution of DR2 red LED's and prefer choice of square shape selected but agree some changes might arise from experimentation.

10) Costing - Recommend reducing quantity to four prototypes, one of which utilizing red DR1 LED's for intensity/range comparison purposes and the remaining three optimized for maximum range for reliable identification of all three colours.

Would you please investigate the impact that these comments might have on the estimated cost of this phase of the project and reply in advance of our next committee meeting planned to be held about the end of February.

TYPE I - OBJECTIVES

Decision Statement: TO CHOOSE THE OPTIMUM TYPE I ARRAY PROTOTYPE

Establish and Classify Objectives.
List the important results to be accomplished, resources to be used and limits to be observed in this decision.

Objectives (MUST)	Relative Importance	Objectives	Relative Importance
1 Minimum Range of 1320 feet	10	13 Use existing beam spreading, deflecting & hot spot accessories	10
2 Three required colours	10	14 Suppression of phantom aspects	10
3 No moving parts	10	15 Maintenance period of at least one year	10
4 Fit existing outer housing (retrofit)	10	16 One lens for all LED's, i.e., not a separate les for each LED	10
5 Minimum Beamwidth of ±2°	10	17 Complete the prototype stage by June 1985	10 ?
6 Light emitting surface completely fill 8 3/8" diameter outer lens	10		
7 Separate LED's for each required colour	10		
8 Redundant configuration of each colour	10		
9 Power Consumption ≤ 18 Watts	10		
10 Materials and Workmanship to ARR Specifications	10		
11 Operate over -40°C to 70° normally	10		
12 Withstand shock, vibration and humidity etc. as expected in railway environment	10		

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TYPE I - OBJECTIVES

Decision Statement: TO CHOOSE THE OPTIMUM TYPE I ARRAY PROTOTYPE

Establish and Classify Objectives:
List the important results to be accomplished resources to be used and limits to be observed in this decision

Objectives (WANT)	Relative Importance	Objectives	Relative Importance
1a Range of 5000 feet 1b Range of 2500 feet	~~5~~ 9		
2b (Colour distinguishability) 2a Correct Chromaticities	9 9		
3 Minimize Power Consumption	~~6~~		
4 Minimize Cost (budget 2360/unit)	5		
5 Manufacturability	~~7~~		
6 Reliability (20 year life span)	~~10~~		
7 Shape of Pattern	~~2~~		
8 Uniformity of Pattern	4		
9 Information of Pattern	1		
10 Maintainability	8		
11 Maximize Beamwidth	3		
12 Mean time between failures greater than one year	9		

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Relative Importances of WANT Objectives ranked by Steering Committee January 17, 1985

TYPE I - LED's

decision statement TO CHOOSE THE BEST LED's (COLOUR RED)

objectives whatever I choose should:		alternatives a DR1			b DR2		
must		info	go/no		info	go/no	
Complete in a reasonable time			✓			✓	
Range of 1320'			✓			✓	
want	wt.	info	sc.	wt. sc.		sc.	wt. sc.
1a Range of 5000 feet	5	2000 mcd, 12°	5	25	500 mcd, 12°	3	15
2 Correct Chromaticities	9	within AAR specs	6	54	within AAP specs	6	54
4 Minimize Cost	5	approx. 12.50 each	1	5	approx. 1.00	5	25
6 Reliability 20 yrs life	10	200,000 hr rated	6	60	200,000 hr rated	6	60
11 Maximize Beamwidth	3	12° beamwidth	3	9	12° beamwidth	3	9
2b Colour Distinguishability	9		5	45		5	45
1b Range of 2500 ft.	9		5	45		3	27
				243 -154-			235 -168-

3RD MEETING OF STEERING COMMITTEE
March 7, 1985

Mr. Lougheed reported that in accordance with the decision reached at the 2nd meeting, the principal thrust in the intervening time has been devoted to improvement to the Type I prototype. In that respect, a specimen custom-made optical glass lens has been obtained, which he displayed. He reported that cost of the specimen was approximately $100 but that production cost would be in the order of $10-$12.

It was reported that an improved array type I has been assembled for testing. That array consists of a total of 199 LED's as follows:

- 33 DR2 (500 milicandela)
- 83 DG1 (200 milicandela)
- 69 DY1 (140 milicandela)
- 14 DO1 (200 milicandela)

Note: DY1 and DO1 are to be lighted simultaneously. DO1 added to bring the chromaticity of the lighted display to within the AAR yellow spec.

Following lunch the Committee proceeded to the test site for a non-scientific distance observation of the new array relative to a standard US&S searchlight. The test site was the same as that used for observation of the earlier array at the 2nd meeting and the test set-up was the same (section 3 of minutes of the 2nd meeting) except that a light pick-up truck rather than a panel truck was used this time.

The two signals (standard searchlight and LED array) were observed by the Committee at distances of 1600, 1200, 800 and 400 metres (approximately 5200, 3900, 2600 and 1300 ft.).

At each location, observations were made of the visibility of each colour of each signal in the steady and flashing modes. At 1600 metres, neither signal could be seen by any of the observers. At 1200, both signals were only marginally visible. For the yellow and green, the standard signal was superior to the LED signal. For the red, visibility of the signals was equivalent. At 800 and 400 metres both signals were fully visible to all observers, all colours, both steady and flashing. Two types of observation were made, i.e., colour, mode and source (standard or LED) as called for by the observers, and then as a random choice by the operator with the observers identifying the display. For the latter type of observation all observers identified all displays without error.

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Votre référence Your file
C84-129
Notre référence Our file
D1465-378-3

March 14, 1985

Mr. J.H. Lougheed
Manager, Electrical Eng.
W.R. Davis Engineering Ltd.
1240 Old Innes Road
Ottawa, Ontario
K1B 3V3

Dear Mr. Lougheed:

This has reference to a series of discussions between Montreal-based committee members and is supplemental to the minutes of our meeting in Ottawa on March 7th.

As noted in item 8 of the minutes, the second prototype's performance under prevailing conditions was most encouraging. Suggestions for possible further improvements for the next Type I prototype unit included the following:

1) increase the proportion of green LED's in the array at the expense of red and yellow LED's.
2) increase slightly the ratio of amber to yellow LED's to further improve the chromaticity of the "yellow" aspect.
3) substitution of brighter reds (DR1) for existing (DR2) reds to reduce the overall number to make room for greens.
4) diffusion of light source by means of a Fresnel lens to improve appearance of red and yellow display when viewed from close range.

Following subsequent discussions, an alternative optical concept was advanced namely: - separation and consolidation of the red, yellow and green arrays in concentric rings (red smallest, green largest) combined with multiple or compound lensing to produce three aspects completely and evenly filling the outer roundel while maintaining appropriate and comparable intensity for achieving the maximum range. It is recognized that this presents a sharp departure from our approach to date, but it is the Committee's opinion that it warrants further experimentation and should be addressed before building the final three prototypes.

/2...

Towards this end, the Committee has developed an alternate pattern for LED's to be incorporated into the third prototype for test at our next meeting. It will accommodate the new optical concept and also the suggested improvements to the second prototype to the greatest extent possible. The attached document illustrates our suggestions.

Additionally, emphasis should be placed on:

1) Advancing the design and fabrication of the first Type 2 prototype.
2) Design of LED drive circuitry ("smart box") to ensure that maximum power consumption is less than 18 watts.

A decision on the fabrication of the final three Type 1 prototypes will be deferred at least until the next meeting.

Following your consideration of the above, it would be appreciated if you would call me for discussion.

Yours truly,

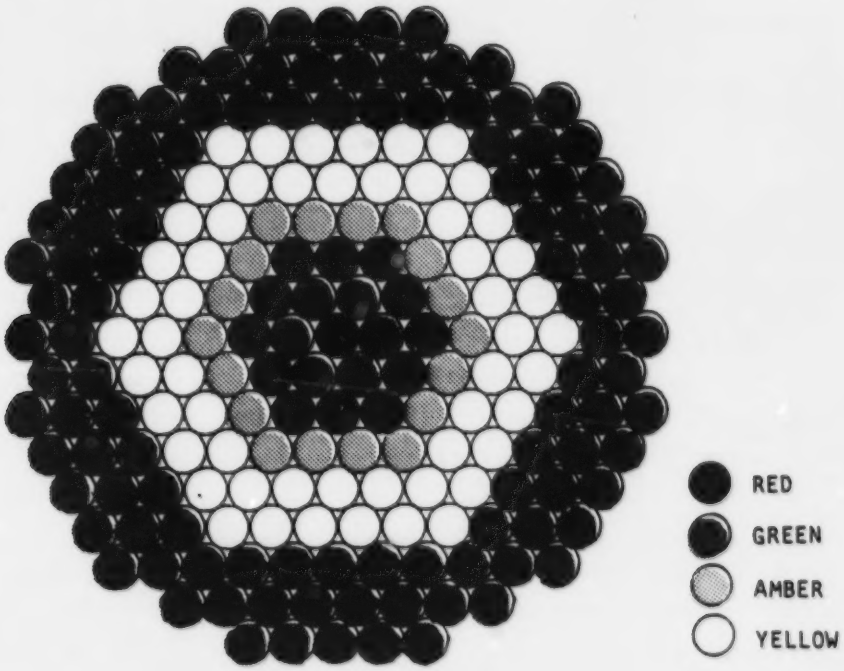
W.G. Rowan

W.G. Rowan
Senior Development
Officer

WGR/cb
Encl;

cc: Messrs.: R.C. Field, CN Rail
E.J. Chapman, CN Rail
R.G. Maughan, Consultant

RAILWAY COLOUR LIGHT SIGNAL
3RD TYPE I PROTOTYPE
199 LED ARRAY PATTERN

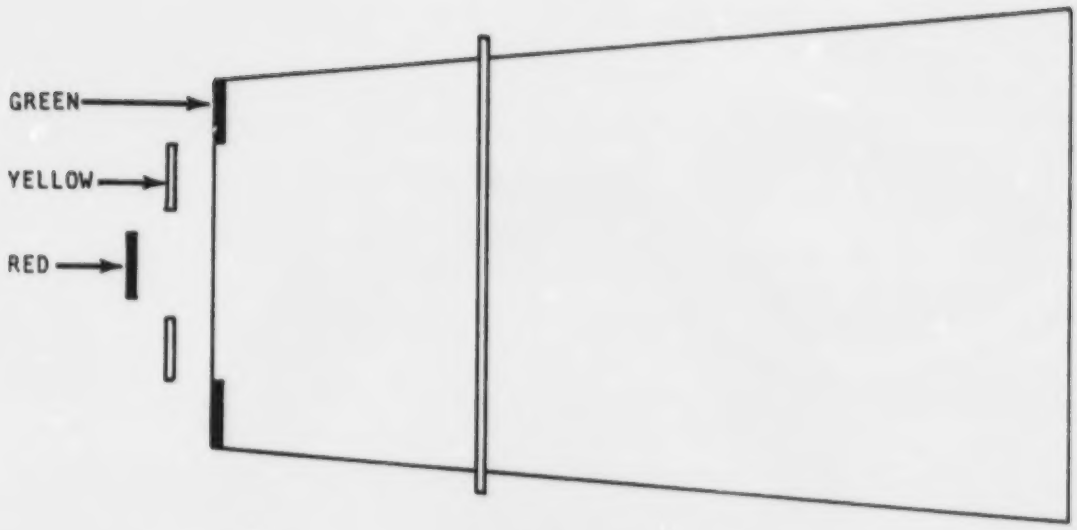


NOTES:

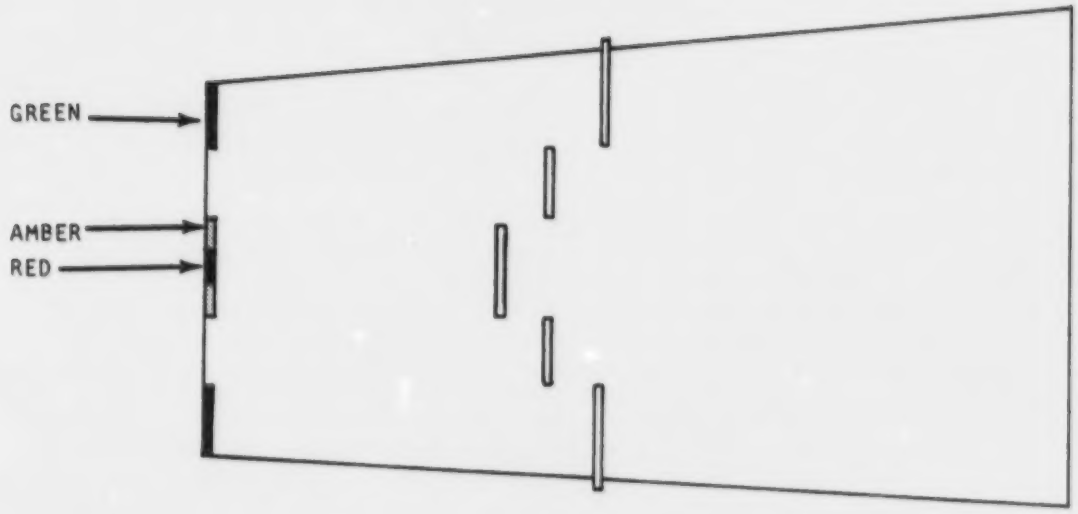
1) CENTRE RED STANLEY H2000 REQUIRES SEPARATE CIRCUIT AND IS ON FOR RED ASPECT AND YELLOW ASPECT WHEN COMBINED WITH 6 CENTRAL GREEN D.D. LEDs.
2) CENTRAL GREENS ARE ADDITIVE TO OUTSIDE GREENS AND DIFFUSED (REQUIRES INDEPENDENT CIRCUITRY AND SWITCH)
3) RING OF 12 STANLEY H2000 REDS DIFFUSED - RED ASPECT ONLY
4) RING OF 18 DD AMBER DIFFUSED - USED FOR YELLOW AND AT LEAST PARTLY (SAY 9-18) FOR RED ASPECT AS WELL
5) 2 RINGS OF 24 & 30 YELLOWS NON-DIFFUSED - YELLOW ASPECT
6) 3 RINGS OF 108 GREEN NON-DIFFUSED - GREEN ASPECT

RAILWAY COLOUR LIGHT SIGNAL - PHASE II

ALTERNATIVE CONCEPT



SINGLE COMPOUND LENS



THREE SEPARATE LENSES

Railway Colour Light Signal

Memorandum of Discussion in R.C. Field's Office - March 12/85

Present: W.G. Rowan
R.C. Field
R.G. Maughan

On the basis of the tests of Prototype #2 on March 7, it had been our initial feeling that insofar as the source array is concerned, the next prototype should be similar (i.e. random pattern) but should:

- include more green to improve visibility at 800 m.
- reduce the yellow/red LEDs in order to provide space for more green while maintaining range through substitution of brighter reds (DR1/DR2) and yellows (DY4), assuming the latter two types will become available later this year;
- increase slightly the ratio of orange to yellow to further improve the chromaticity of the yellow (less greenish, more reddish)
- incorporate LED drive circuitry so that maximum power consumption is less than 18 watts for steady state display of any aspect

However, such an arrangement would still leave us with two significant disadvantages:

- discernment of range LED's in the yellow display at close range and
- "spottiness" of red display at close range.

Both of these disadvantages might possibly be overcome through the use of a diffuser (Fresnel lens) while sacrificing range.

In the case of the reds, this would not be too serious because we are able to compensate for the loss by moving to 2000 milicandela LED's, but the option is not open to us in the case of the greens and yellows.

A solution would be to collect the red display at the centre of the array and diffuse only it. This would eliminate the "spottiness" of the reds, but still leave us a spotty yellow at close range (orange LED's intermixed). However if the orange LED's were included with the central red display and both the reds and the oranges diffused and, additionally, the circuitry arranged so that the diffused orange LED's lighted with the yellows, that problem would also be overcome. Furthermore, if a few greens were added to the central display and these plus some of the reds also lighted with the orange and yellows, the chromaticity of the yellow should be further improved. A further improvement could be achieved by lighting some or all of the oranges with the reds (for the red aspect), thereby moving the chromaticity of the red aspect closer to the centre of the AAR band.

Inasmuch as all of the yellows and all of the greens (except for the few greens in the red display) would necessarily be positioned outside of the circumference of the red display, there is a question in our minds as to whether, even with the new lens just obtained by Davis, the front of the signal would be filled by either the yellow or green display, or whether there would be an unlighted or very "weak" spot in the centre. Also, for the red display, whether there would be a "weak" ring at the outer edge.

Insofar as the yellow and greens are concerned there are two possibilities. They could be either intermixed or placed in two separate colour rings with the greens at the outside (because of their greater number). If this were done, it would seem that the greatest possibility for a "weak" central area would be with the greens.

In spite of these adverse possibilities, it is felt it would be valuable to make the next array in this way; i.e. a central red, rings of yellows outside of the reds and finally rings of green outside of the yellows. If "weak" spots in any or all of the aspects result, multiple or compound lensing to eliminate them can be considered.

4TH MEETING OF STEERING COMMITTEE
April 23, 1985

Mr. Lougheed reported on the following matter with respect to the Type 1 prototypes:

In order to make the visibility test more objective, masks were made up for the conventional signal to reduce the light transmission at distances of 400,800 and 1200 metres from the viewer so that at those distances, the visibility of the signal was equivalent to the visibility at 1600 metres. The mask for the 1200 metres distance permits 50% light transmission, for 800 metres 40% light transmission and for 400 metres, 10%.

The Type 1 prototype #2 was then compared with the masked conventional signal at the test site at distance of 1200, 800 and 400 metres. The observed brightness of prototype #2 relative to the conventional searchlight signal under those conditions was observed to be as shown below:

Brightness of Prototype #2
Relative to Conventional Signal

Distance from Observer (m)	400	800	1200
Red	2 times	3 times	same
Yellow	1.5 times	0.8 times	0.25 times
Green	same	0.8 times	0.25 times

Tests for phantom images were conducted by shining a white light into the conventional signal and into the prototype #2. It was found that:

a) For the conventional signal, a dim phantom image of the coloured roundel in position was discernable.

b) For prototype #2

i) No colour phantom was discernable, but a white reflection of the exterior light was discernable.

ii) When the plano convex lens was reversed so that the plane side was away from the LEDs, not even the white reflection was discernable.

Concerning the configuration for Type 1 Prototype #3, the contents of Mr. Rowan's letter of March 14, 1985 was reviewed. It was concluded that the alternative concept outlined therein and illustrated in Annexes 2 and 3 to the letter was not possible from the standpoint of optics.

Instead, a third prototype array was assembled, similar to prototype #2 but with the following number of LEDs:

97 DG1
83 DO1
19 DR1

This array was tested for brightness in the field in the same matter as for prototype #2 described in the paragraph above. It's brightness relative to the conventional signal was found to be as shown below.

Brightness of Prototype #3
Relative to Conventional Signal

Distance from Observer (m)	400	800	1200
Red	2 times	2	3
Yellow	3	0.9	0.5
Green	3	0.9	0.7

NOTES:

1. The prototype #3 yellow was quite reddish.
2. Drive circuit efficiency for prototype #3.

Now Draws	Can Be Redesigned To Draw
Red 15 ± watts	4 watts
Yellow 50 ± watts	14 watts
Green 60 ± watts	16 watts

Mr. Lougheed reported that they gave given preliminary consideration to the Type II prototype design. It is their present thinking that the first prototype would consist of 150 LED's with individual lenses (lenses are on hand). For the final design, a single lens would be used. A 9" x 9" square roundel would be utilized along with a uniform symmetrical pattern for each colours source.

Following lunch, the Committee proceeded to the test site for observation of the brightness of the Type 1 prototype #3 relative to the conventional URSS searchlight. For this purpose, the conventional signal was masked as described in paragraph 2.1 above. Concensus of the individual observations was as follows:

Brightness

400 m — All colours for both signals clearly visible

Red-prototype much brighter than conventional
Yellow-brightness of both signals roughly equivalent
Green prototype slightly brighter than conventional.

800 m — Red-both signals clearly visible. Prototype slightly brighter than conventional.
Yellow-conventional clearly visible. Prototype only marginally visible.
Green-conventional clearly visible. Prototype only marginally visible.

1200 m — Not compared.

Colour - Prototype yellow too reddish
Prototype green appeared to be the same as the conventional green (blue sky, clear, no snow on ground)
- Prototype red same as conventional.

Spottiness of prototype (i.e. ability to discern individual LED's in the array).

- red - discernable at between 30 - 60 m
- yellow (amber) - discernable at about 30 m.

It was agreed that the contractor would proceeds as follows:

Arrange for a brief comparative visibility test of two signals during darkness to confirm that comparative findings are similar to day time results, particularly to ascertain if the green aspects appeared identical or the AAR aspect appeared more bluish. It was mentioned that a scientific explanation of any chromaticity variances from existing specifications would be necessary to support the new signals.

Investigate the optical ramification of changing the front lense for the next Type 1 prototype and revert to mixing sourced LED's to produce yellow aspect and a narrower, more luminous beam.

Proceed with assembly of the first Type II prototype unit.

C84-129

TYPE I LED SIGNAL - ADDITIVE OPTICAL CONCEPTS

PROBLEM - desire optical scheme to add, say, yellow and amber LEDs to achieve correct chromaticity without visible separation. (In a larger context, same would disguise physically separate banks of LED colours - see Steering Committee notes of March 12, 1985 and Annex '3' of March 7, 1985 minutes).

Possible solutions raised:

(a) separate internal lenses to provide overlap at front lense

(b) separation in space of array rings with mixing by de-focussing

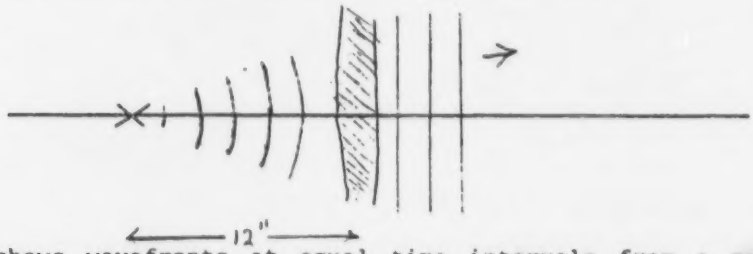
(c) beam combining

Note diffraction/diffusion/fresnel techniques were previously explored but exacted large brightness penalties and spread the beam.

(a) Separate internal (1st) lenses

- examine the requirements for reasonable focus of the 2nd (large, objective, 8 3/8 in.) lense to determine the requirement of each 1st lense.

- 8 3/8 in. lense has 12 in. focal length, i.e.



Above shows wavefronts at equal time intervals from a point source at the focus, resulting in a well-collimated (narrow) beam.

- this representation may be better than ray-tracing for our purposes as it illustrates how the whole lense is involved and influences any source, whether exactly at focus or not.

- looking back into searchlight, one would see a magnified image of the source filling the whole 8 3/8 in. area.

- next, replace the point source with an array of sources; magnified image (when adjusted for a collimated output beam) will show all sources, magnified as appropriate but still separated one from another (eg. current array seen via internal lense).

- finally, replace array with 3 separate lenses and appropriately modified array (rings etc); the image which gets magnified and projected is of 3 separate lenses regardless of what they do to the LEDs behind them, i.e. one will see 3 pieces of glass.

- this does not satisfy our requirement to have each set of LEDs visually overlaid, filling the whole objective with each colour.

(b) Mixing by de-focussing

- one lense, 3 separate planes of LEDs for example.

- there is no doubt that a source sufficiently de-focussed can have its image disguised, therefore two or more sources de-focussed can have overlapping, disguised images which the eye will mix.

- but the trick is to de-focus without destroying collimation, otherwise the output beam will broaden and brightness will drop.

- therefore, insert a first lense which de-focusses the array image, and focus the 8 3/8 in. objective lense on this first lense, to keep the beam collimated.

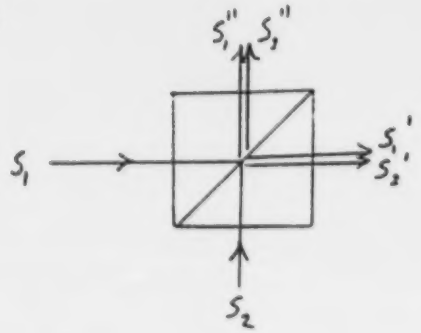
- result: the output will be as collimated as ever and losses from the 2nd lense will be small; however, the brightness loss has already occurred at the first lense and cannot be regained.

- result: a well-collimated but weak output.

(c) Beam Combining

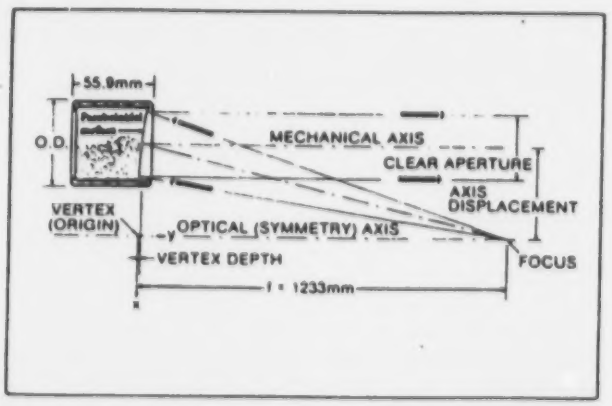
- optical devices for combining images or beams without much distortion do exist; beamsplitting prisms are one, and off-axis parabolic mirrors (which also collimate) are another.

Beamsplitter



- source S_1 is split into S_1' and S_2'', similarly source S_2.
- either output (S_1' + S_2') or (S_1'' + S_2'') will be an overlaid image as we desire.
- split ratio can be unequal,
  eg. S_1' = 80%, S_1'' = 20%
  (transmitted) (reflected)
- however, <u>same</u> split ratio will hold for S_2;
  S_2' = 20% (reflected)
  S_2'' = 80% (transmitted)
- thus one or the other or both inputs will suffer loss, and on average we will obtain only 50% out.

Off-Axis Paraboloid



- allows sources to get out of way of output beam
- sometimes used with parabolic mirror placed within another beam
- viewed from right, source will apparently be behind the mirror
- this will not combine beams in the sense of mixing; unless something else is done, the image of the off-axis source will be distinct (but displaced)

Conclusions:

1) the lense systems proposed in Annex '3' can't achieve what is needed without a drastic range penalty.

2) a beamsplitter (combiner) will overlap images of two (or more) sources, but at a cost of 50% of the light lost and some mechanical complexity (sources mounted at right angles).

Therefore I conclude that no scheme known to me is worth the penalties, except possibly using a beamsplitter to add small amounts of, say, amber to yellow. I would not recommend trying to beamsplit 2 ways (eg. Red, Green overlapped images with both on for yellow) because it would still leave each LED of the reds and greens visible at close range.

J.H. Lougheed

PROTOTYPE #2 - RANGE TESTS

On April 11, 1985, range tests were performed on the 199 LED array which consisted of 33 DR2 red, 83 DG1 green, 69 DY1 yellow and 14 DO1 orange light emitting diodes. The yellow and orange were operated together for the yellow aspect. The plane-concave lense used was glass with a focal length of 116 mm and a radius of 60.3 mm and a diameter of 94 mm.

The purpose of these tests was to establish a standard by which to compare all subsequent arrays. Also the range of the 199 LED array was established using the standard. It was also a confirmation of the range tests done less formally at the end of the last Steering Committee meeting on March 7th.

Prior to the actual test care was taken to ensure the LED array was correctly aligned. It was discovered that the lense had not been properly centered with respect to the front lense and this problem was corrected. The method of alignment used was simple. A pre-measured wire whose length was calculated as being the correct spacing between the lenses was used to ensure that this spacing was correct. An improvement was also made on the sighting of the light.

In order to establish a standard by which to compare all subsequent arrays a jig was affixed to the existing signal light and various masks made up to block the light to various degrees in approximate 10% intervals.

The actual tests were performed on Anderson Road east of Ottawa, just south of Highway 417. It was a sunny day with scattered clouds. The testing lasted from approximately 13:30 to 15:30 hours.

After initially lining up of the two lights at close range and establishing the 400, 800, 1200 and 1600 m marks the conventional light was viewed at 1600 m. Further lining up was carried out before moving to 1200 m where the attenuating mask necessary to visually perceive the light as being the same at 1600 m was established. For yellow a 50% attenuator mask was required. For red, a 50% attenuator mask was slightly brighter while 40% was too dim. For a green a 40% mask was equivalent.

At 800 m, a 20% mask was slightly dimmer than the conventional 1600 m. At 400 m a 10% mask was still too bright for all three colors.

Using the 10% mask at 400 m, the 40% mask at 800 m and the 50% mask at 1200 m, the 199 LED array was rated for its relative brightness in order to determine its range.

At 400 m the yellow was about 1½ times as bright, the red was more than 2 times as bright and the green was about the same brightness. At 800 m, both the yellow and green were about .8 of the conventional light and the red was about 3 times as bright. At 1200 m the yellow and green were about ½ as bright while the red was about the same.

From the beginning to the end of the tests the voltage and current levels for the conventional light changed from 10.6 V at .99A to 10.63 V at .97A.

As an additional check for some colors the blocking screen was changed to give the same relative brightness at a given distance.

At 400 m the yellow array was just slightly dimmer than the conventional light at 20% attenuation. The red array was equivalent to a 40% attenuated conventional signal.

At 800 m the red array was equal in intensity to the conventional at 50% attenuation.

RELATIVE BRIGHTNESS

COLOUR	10% CONVENTIONAL at 400 m	40% CONVENTIONAL at 800 m	50% CONVENTIONAL at 1200 m
Red	2^{+}	3	1
Yellow	1.5	0.8	.25
Green	≈1	0.8	.25

Relative Brightness is $\frac{\text{Array}}{\text{Conventional}}$

From the results obtained, the following can be concluded.

1. The standard to be used for comparison of arrays should be

   at 400 m - approx. 5% attenuation (to be checked with a new blocking screen)

at 800 m - 40% attenuation

at 1200 m - 50% attenuation

These agree well with the expected values of 6.3% and 56.3% for 400 and 1200 m respectively but not with the 25% expected for 800 m.

2. The prototype #2 used has a range of 1200 m for the red and nearly 800 for the green and yellow with green the poorest.

PROTOTYPE #3 - RANGE TESTS

On April 19, 1985, range tests similar to those performed for Prototype #2 on April 11, were done for prototype #3. This day was unlike April 11, with the sky completely overcast.

Based on the previous tests and having made a new blocking mask of roughly 5% attenuation, the masking of the conventional light used was:

5% at 400 m
40% at 800 m
50% at 1200 m

The new array - Prototype #3 had:

97 Green - DG1
83 Orange - DO2
19 Red - DR1

The results were:

RELATIVE BRIGHTNESS

COLOUR	10% CONVENTIONAL at 400 m	40% CONVENTIONAL at 800 m	50% CONVENTIONAL at 1200 m
Red	>>	2^+	3^+
Yellow	2^+	≈.9	.5
Green	3^+	≈.9	.67

Relative Brightness is $\frac{\text{Array}}{\text{Conventional}}$

Noted during this test was that the orange could possibly be mistaken for red and is therefore poor as a yellow aspect.

Also tested was the bare array of 42 Stanley H2000 and it was clearly visible at 800 m.

84-129

VISUAL TESTS - GREEN ARRAY

OBJECTIVE - to see if apparent colour of green LEDs remains close to tungsten under different viewing conditions.

BACKGROUND - prototypes #2 and #3 were noted to present very similar green colour to the standard signal, once it had been stopped down (by a mask) such that brightness was comparable. (Masks are available to provide a "just visible" signal at 400, 800 and 1200 m, matching the un-masked brightness at 1600 meters (1 mile)).

Tests to date have been done in full daylight (clear sky, sun near zenith) and although the standard signal is visibly blue-green at short range, by about 10 m the difference is diminishing and beyond about 30m it is difficult to say there is a colour difference. (To make these observations it is necessary to keep brightnesses comparable; sometimes the coarse masks mislead at short range, since the standard signal has hotspots which appear white through one slit).

POSSIBLE CAUSES - why does the 'bluishness' of the standard signal disappear when viewed at range?

Speculations include:

a) scattering of blue components more than others (Raleigh scattering)

b) chromatic aberration of the eye, with poorer focus of blue components

c) adaptation to sky or earth colours. It was suggested to do a test at night to observe whether or not similar impressions of colour matching occurred.

NIGHT TEST - on May 2, 1985 a conventional signal and prototype #3 board were tested side-by-side after sunset; the night was clear, cool and moderately windy.

The two signals were initially set up locally, with 330 m available range, in the expectation that the blue hue would fade as quickly as during the day.

When this did not happen, the test was moved to Anderson Road for sightings at 400 and 800 m.

RESULTS - at night, with the conventional signal attenuated by masks to provide roughly equal brightness, a distinct difference in colour is perceived at all ranges. The tungsten signal does not appear to be as blue-dominated (or white) as when viewed at full brightness at close range, but is nonetheless obviously 'bluer' than the LED array.

Neither observer (Lougheed, McKinnon) felt the LED green could be mistaken for yellow, whether viewed alongside the tungsten green, yellow or red.

The impression of the tungsten yellow at night was one of appreciable orange content, although not nearly as orange as prototype #3's yellow (= amber).

Prototype #3's yellow (= amber) was clearly unsatisfactory, being easily mistaken for red unless a comparison red was available.

CONCLUSIONS

a) the good green-green match does not hold after dark, pointing towards an adaptation rather than physical cause for the daylight match.

b) neither observer would confuse the green LED signal with another colour.

5TH MEETING OF STEERING COMMITTEE
August 29, 1985

Prof. Tansley reported on his trips on the head end of passenger trains between Ottawa and Montreal. He confirmed that the range of the green signal aspect on conventional signal is less than that of the red or yellow.

Taking into account the project expenditures to date and the limited remaining resources, it was agreed that the contractor will give priority to providing the following of the deliverables specified in the contract:

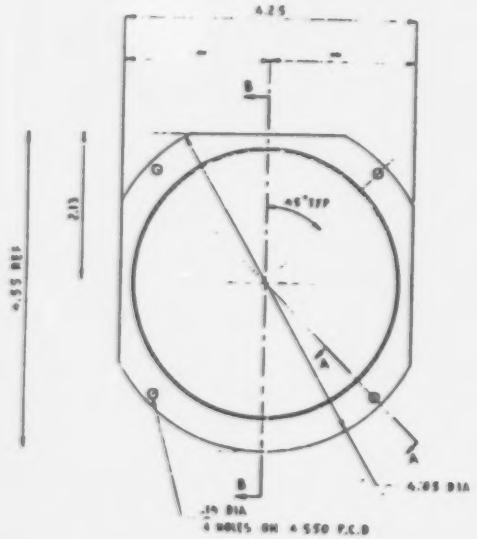
Two Type 1 arrays as described below. One of these shall be wired and mounted in a conventional searchlight signal housing. The second shall be similarly complete but not mounted in a housing. Both arrays will consist of:

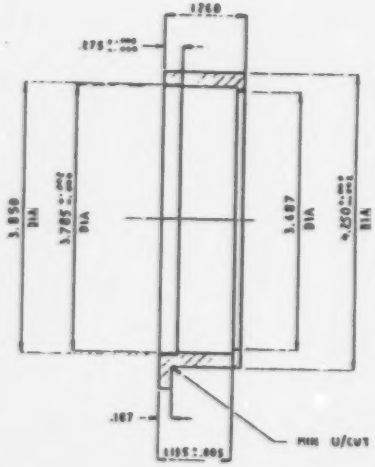
97 DG1
83 DY1
19 DR1

One Type 2 breadboard unit adequate to demonstrate the concept agreed upon previously.

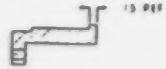
APPENDIX D

TYPE I - DRAWINGS, LAYOUTS AND SCHEMATICS





SECTION B-B



SECTION A-A

NOTES:
1. REMOVE BURRS & SHARP EDGES
2. MATERIAL : AL 6061-T6

DESIGNED		DATE	Davis Engineering	
DRAWN	H TRAN	DATE 15 JULY 85		
CHECKED	RV	DATE 85-Aug-13	LENSE HOLDER MODIFICATION	
APPROVED		DATE	CONT. NO. 84-129	CONTRACT NAME CN PHASE II
QA APPROVED		DATE	CLIENT	DRAWING NUMBER DE 2739

UNLESS OTHERWISE SPECIFIED
1 DIMENSIONS ARE IN INCHES
2 TOLERANCES
DECIMALS .xx ± .03, .xxx ± .015
ANGLES ± 0°-15'
3 SURFACE FINISH
4 ORIGINAL SCALE 1/1
HOLE DIEDS ± .01
HOLE CENTRES ± ——

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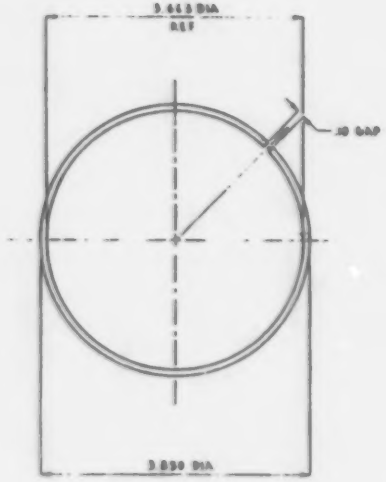

NOTES:

1. REMOVE BURRS & SHARP EDGES
2. DEVELOPED LENGTH 11.70
3. MATERIAL: POLYPENCO TFE 4" OD TUBE

DRAWN	M TRAN	18 JULY 85	Davis Engineering	
CHECKED	RV	85-AUG-13	SPACER MODIFICATION	
APPROVED			CONT. NO. 84-129	CONTRACT NAME CH PHASE II
QA APPROVED			DRAWING NUMBER DE 2740	REV
			SIZE A2	SHT 1 OF 1

UNLESS OTHERWISE SPECIFIED
1. DIMENSIONS ARE IN INCHES
2. TOLERANCES
DECIMALS .XX ± .03, .XXX ± .015
ANGLES ±
HOLE SIZES ±
HOLE CENTRES ±
3. SURFACE FINISH
4. DRAWING SCALE 1/1

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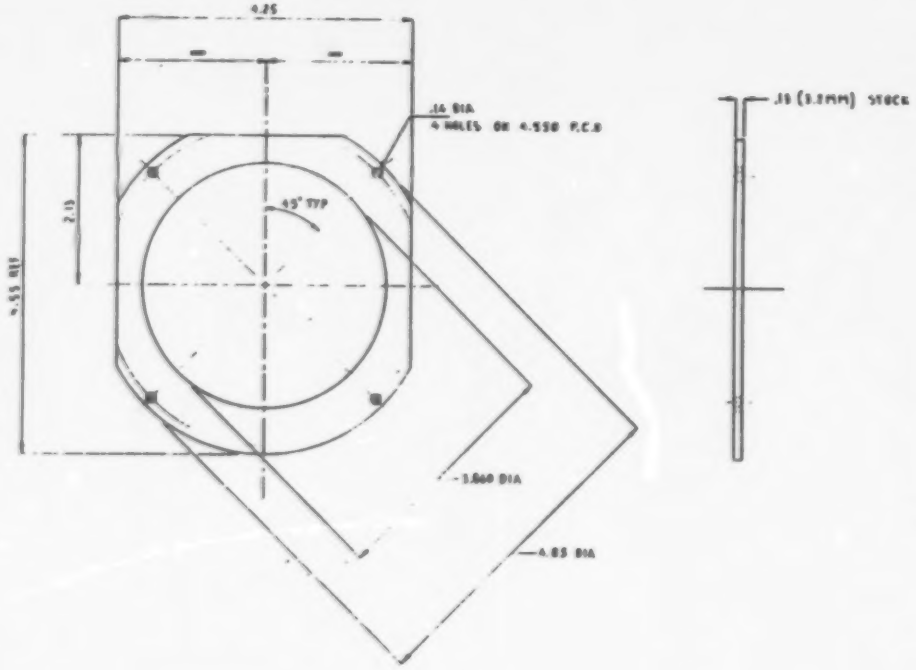
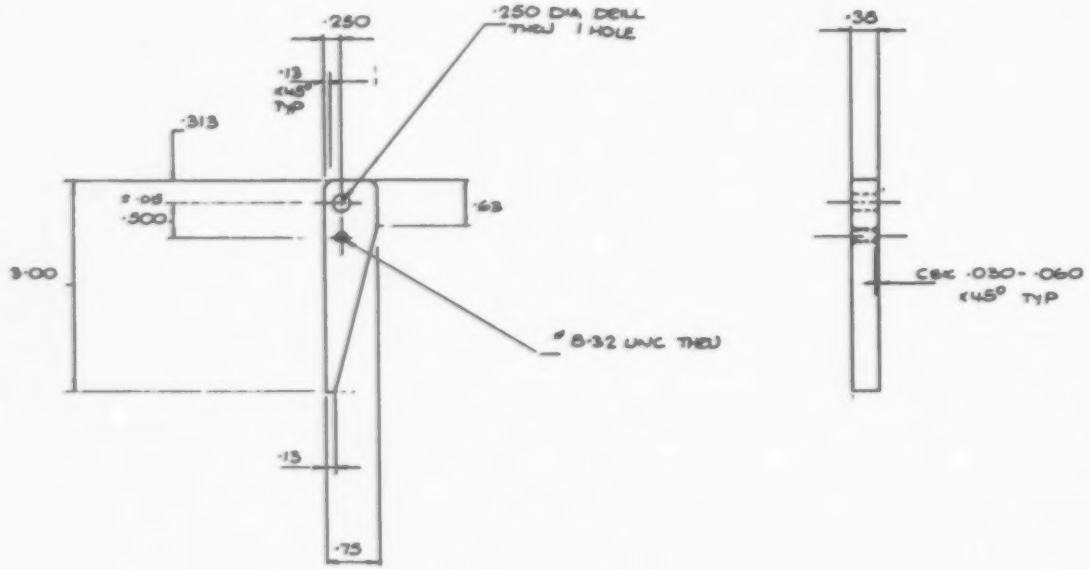
DRAWING APPROVAL



MATERIAL : SILICONE CLOSED - CELL SPONGE SHEET

H TRAN	31 JULY 85	Davis Engineering	
	85-AUG-13	LENSE HOLDER WASHER	
		D4-129 / CH PHASE II	DE 2857

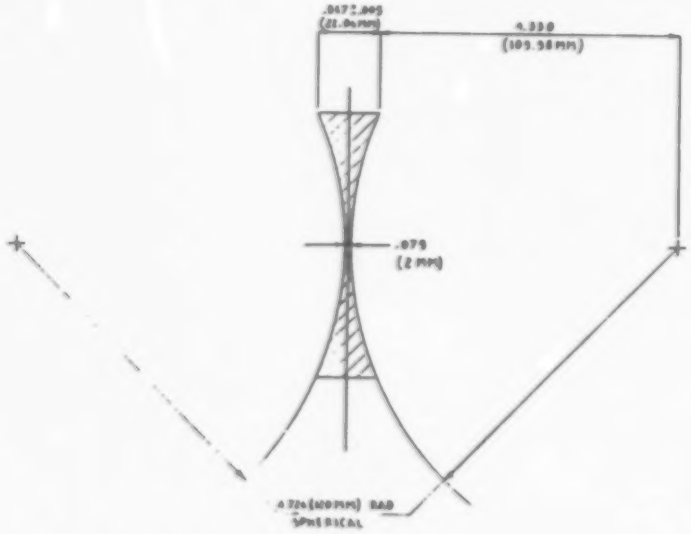


Drawn	BT
Checked	MJ
Date	APRIL 84
Sheet	1/1
Material	ALUMINUM
Size	A2
Drawing Number	DE 2242

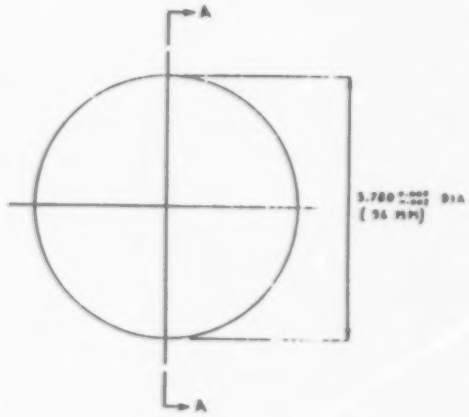
Davis Engineering

LEVER

-DS-



SECTION A-A



NOTE :

MATERIAL : CROWN GLASS
INDEX OF REFRACTION 1.523

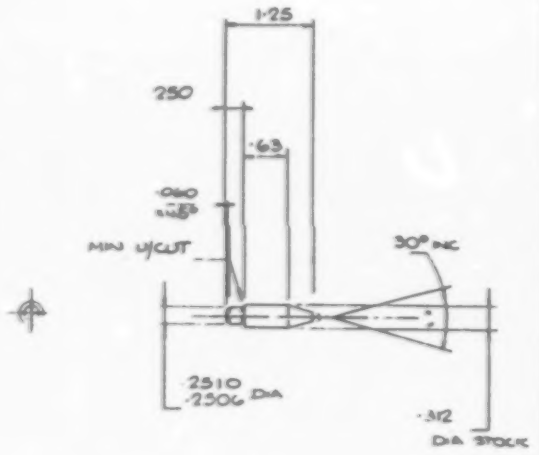
UNLESS OTHERWISE SPECIFIED
1. DIMENSIONS ARE IN INCHES
2. TOLERANCES
DECIMALS ± .0 ——— ± .00 ± .006
ANGLES ± ———
HOLE DIAS ± ———
HOLE CENTRES ± ———
3. SURFACE FINISH √
4. ORIGINAL SCALE 1/1

DRAWN	H TRAN	10 JULY 85
CHECKED	RV	05 AUG 85

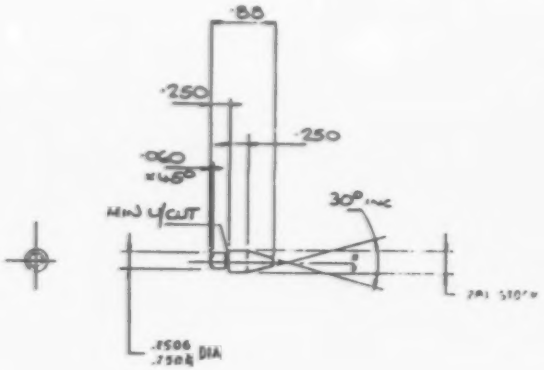
Davis Engineering

LENSE — DOUBLE CONCAVE

84-129 | CN PHASE II | DE 2742 | A2

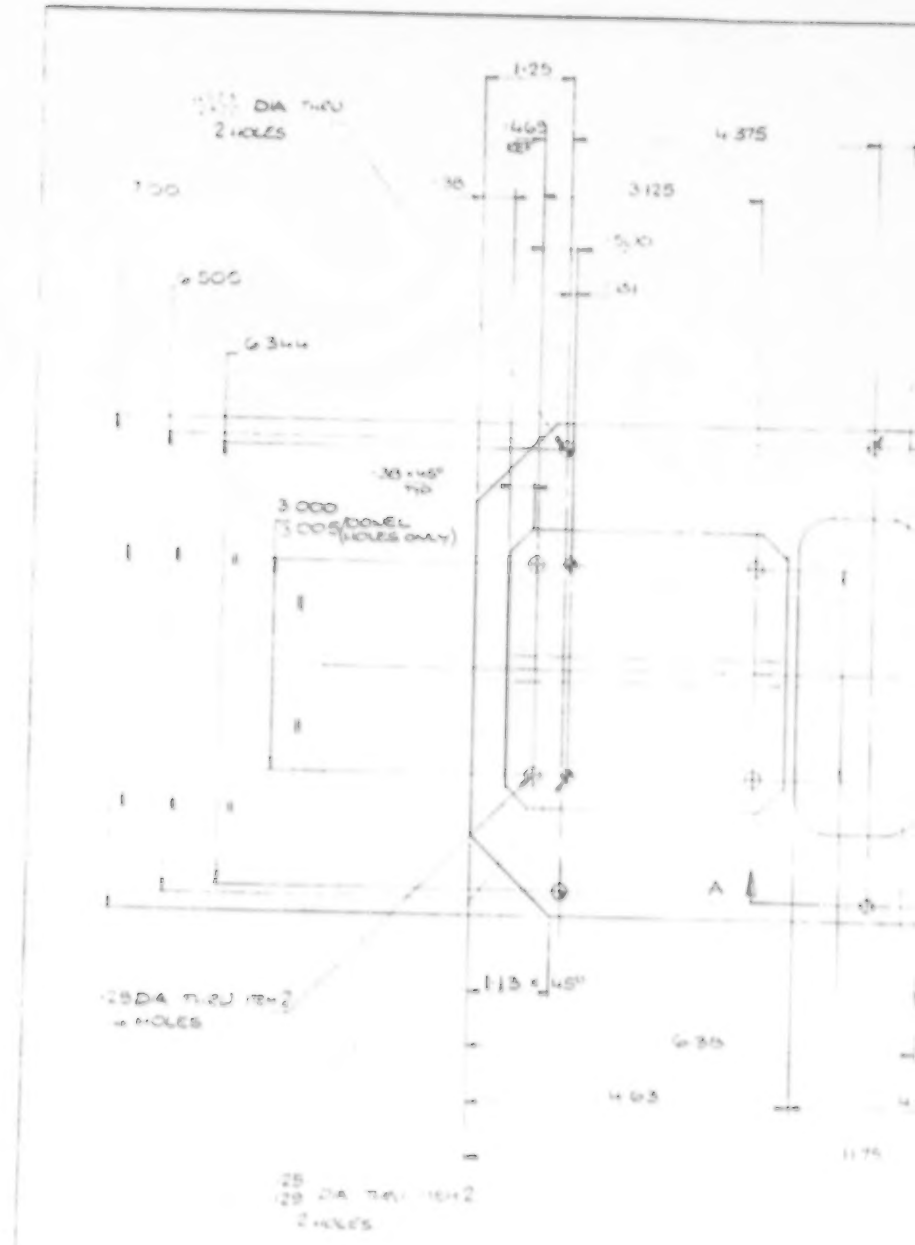


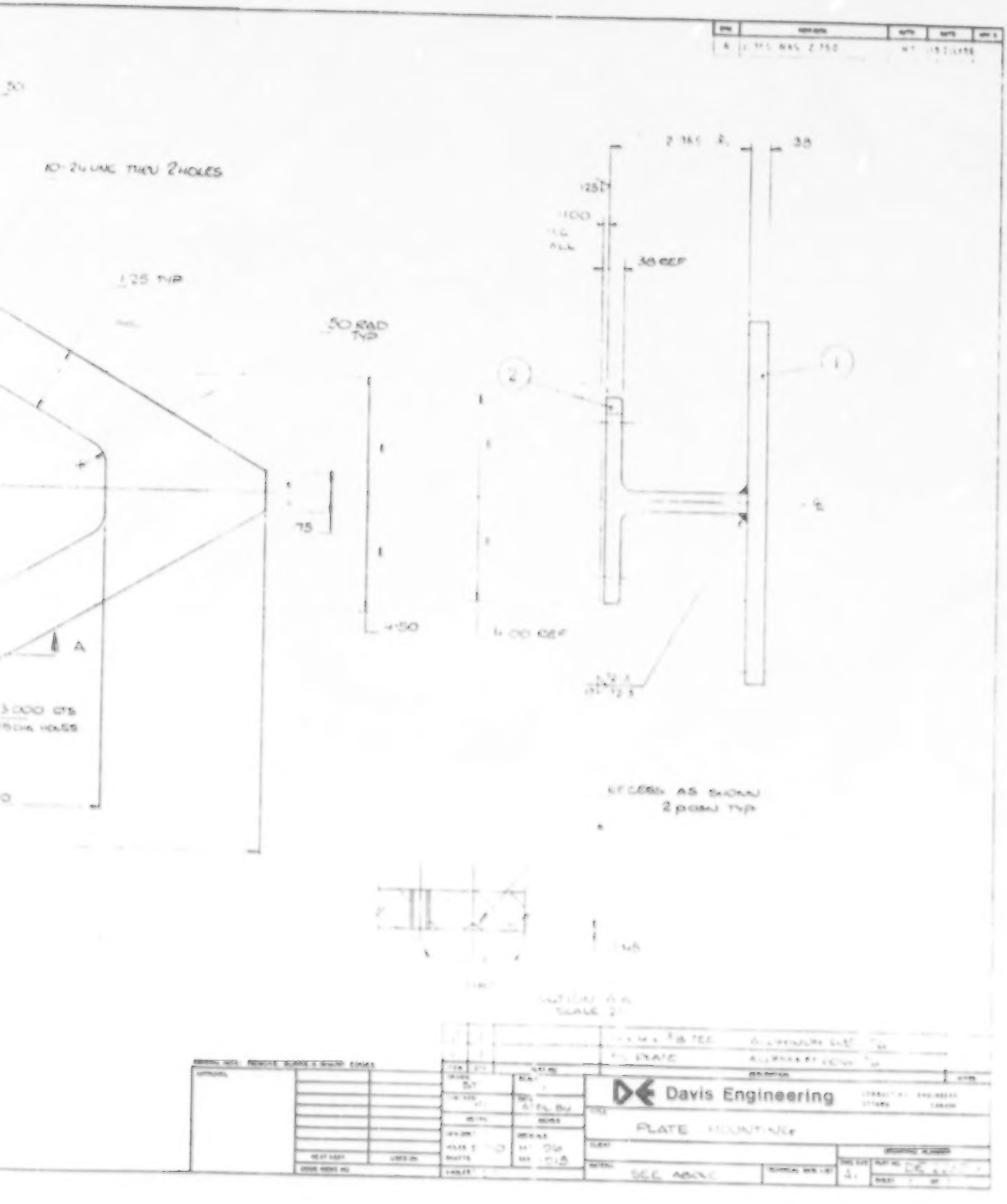
DE2240-1 MAT'L ST ST TYPE 304

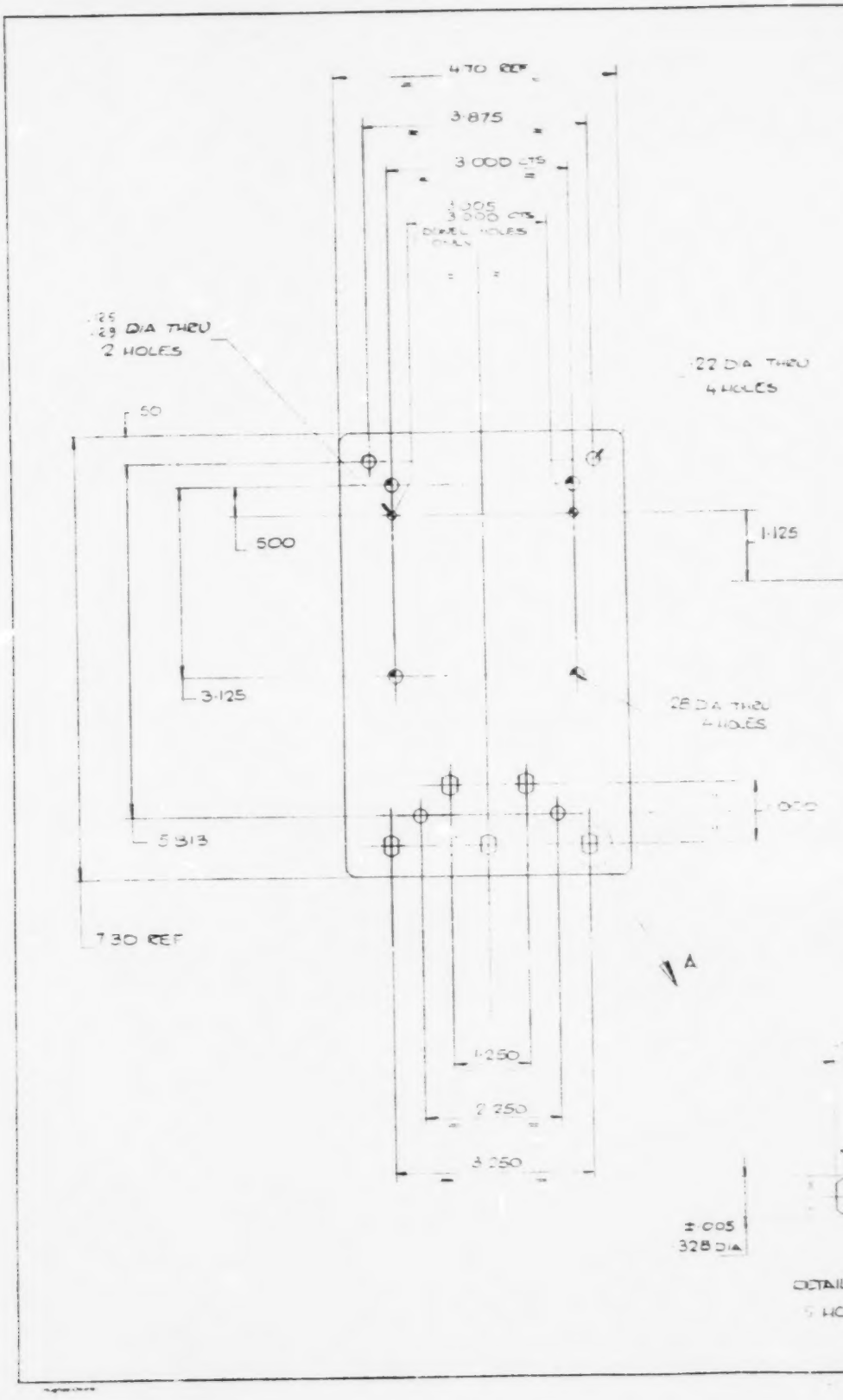


DE2240-2 MAT'L ST ST TYPE 304

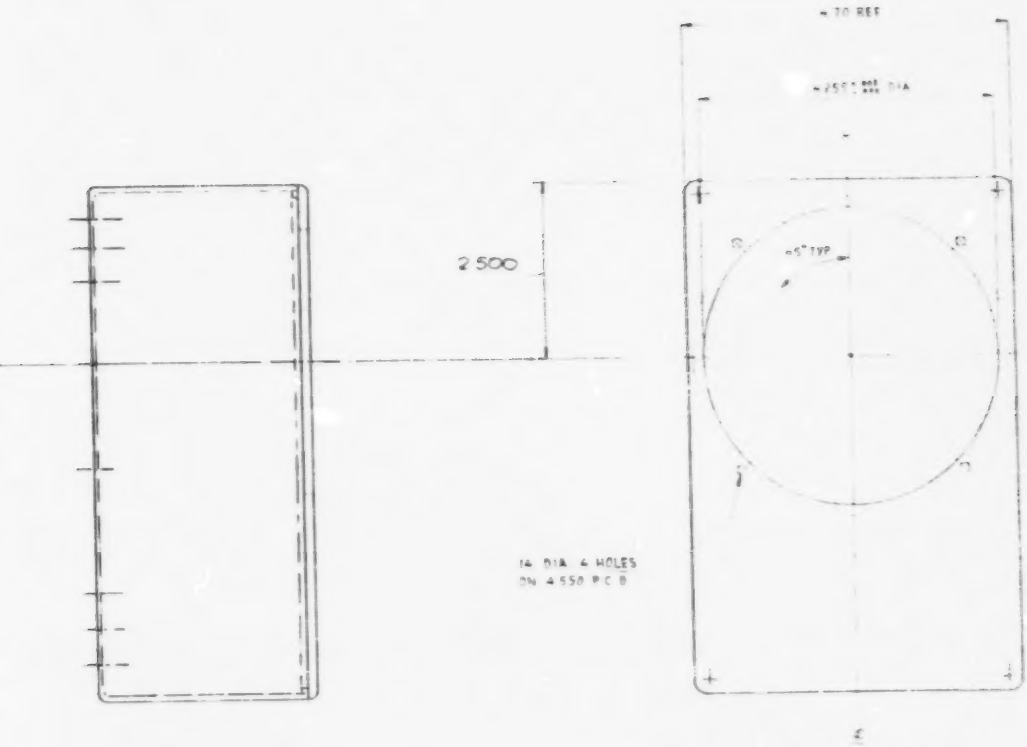
DRAWN	ST	SCALE	1/1	Davis Engineering		CONSULTING ENGINEERS OTTAWA CANADA	
CHECKED	RS	DATE	APRIL 84	TITLE	PIN LOCATING		
MATERIAL		FINISH		CLIENT		DRAWING NUMBER	
TOLERANCES	FRACT ±.060 DEC ±.030 ANGLES ±.5°			MATERIAL	ST ST TYPE 304	TECHNICAL DATA LIST	SIZE A2 DE2240
							SHEET 1 OF 1


DIA THRU
2 HOLES
1.25
4.375
3.125
6.500
3.000
DOWEL
(HOLES ONLY)
A
DIA THRU
HOLES
1.13
45°
6.38
4.63
25
DIA THRU
2 HOLES


10-24 UNC THRU 2 HOLES
.25 TYP
.50 RAD TYP
75
A
SECTION A-A
SCALE 2:1
Davis Engineering
PLATE MOUNTING
SEE ABOVE


4·70 REF
3·875
3·000 CTS
±·005
3·000 CTS
DOWEL HOLES
·25
·29 DIA THRU
2 HOLES
·22 DIA THRU
4 HOLES
·50
·500
1·125
3·125
·28 DIA THRU
4 HOLES
·500
5·313
7·30 REF
A
1·250
2·250
3·250
±·005
·328 DIA

BY	REVISION	CHK'D	DATE	APP'D
A	GENERAL REVISION	ST	83OCT85	



MATERIAL :-

HAMMOND DIE CAST BOX 1590E

± .005

A

ES TYPICAL

GENERAL NOTE: REMOVE BURRS & SHARP EDGES

ITEM	QTY	PART NO	DESCRIPTION	NOTES

DRAWN	ST
CHECKED	RV
SCALE	
DATE	20 AUG 13
METRIC	INCHES
DECIMALS	
HOLES ± .010	.060
SHAFTS	.015
ANGLES °	

Davis Engineering — CONSULTING ENGINEERS, OTTAWA, CANADA

TITLE: BOX MOUNTING

CLIENT:

MATERIAL: SEE ABOVE

TECHNICAL DATA LIST:

DRAWING NUMBER

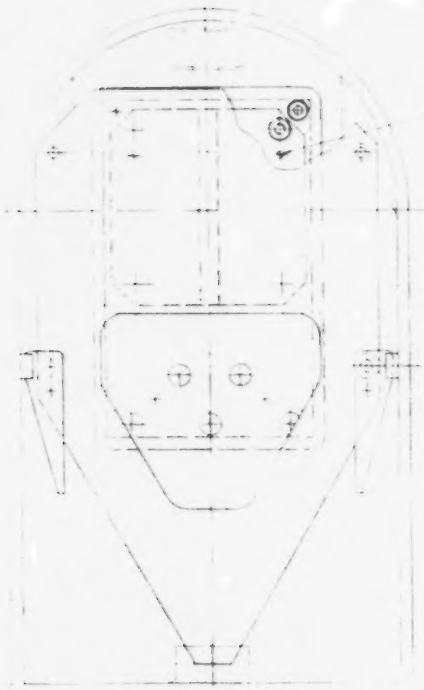
DWG SIZE: A1

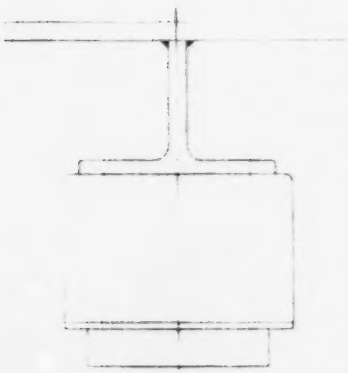
PART NO: DE 4236 .B

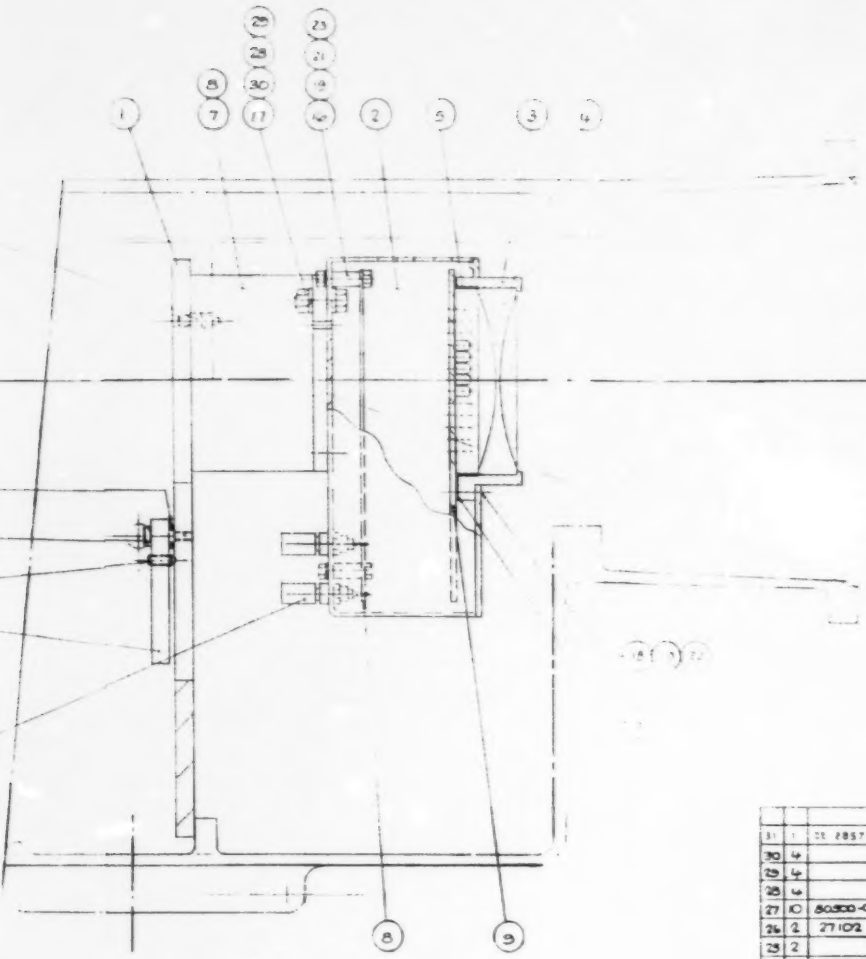
SHEET 1 OF 1

NEXT ASSY | USED ON

CODE IDENT NO.







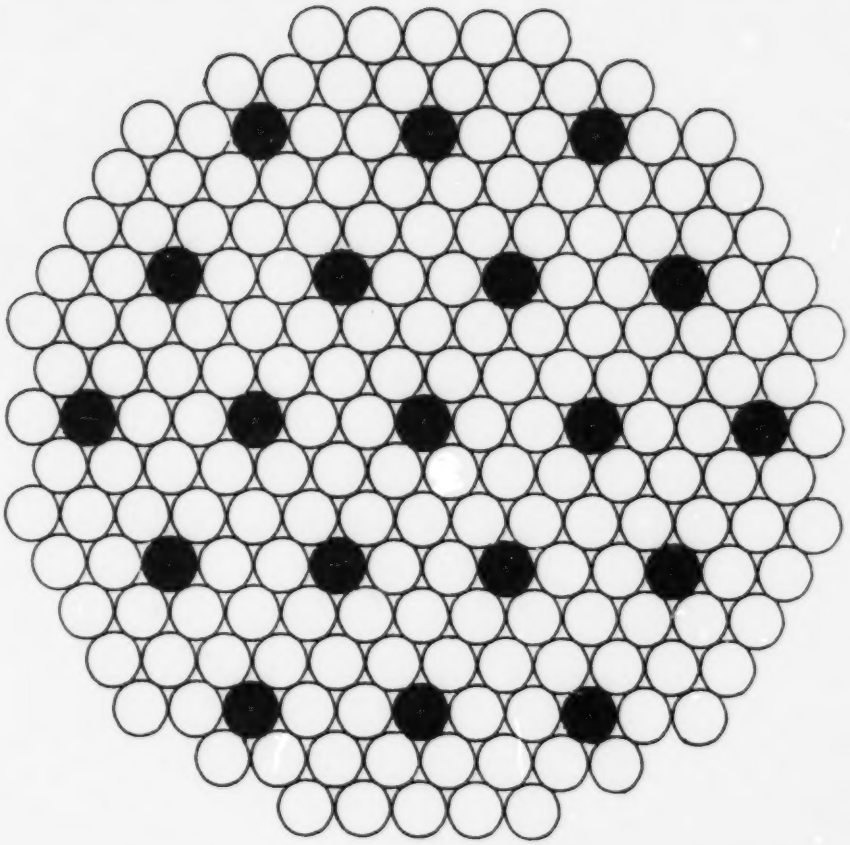
31	1	DE 2857	LENSE HOLDER WASHER	
30	4		NUT HEX ¼-20UNC	STEEL ZINC P.
29	4		WASHER FLAT ¼ NOM	STEEL ZINC P.
28	4		WASHER LOCK ¼ NOM	STEEL ZINC P.
27	10	80500-0186	SPRING WASHER	
26	2	27102	SPRING PLUNGER	
25	2		SCREW SHOULDER ¾ DIA x ½ LG	STEEL
24	2		SPRING TENSION PIN	STEEL
23	4	606-N8	SPACER PHENOLIC	
22			NUT HEX	STEEL ZINC PL
21	4		NUT HEX #10-24 UNC	STEEL ZINC PL
20			WASHER LOCK #4 NOM	STEEL ZINC PL
19	4		WASHER LOCK #10 NOM	STEEL ZINC PL
18			SCREW HEX	STEEL ZINC PL
17	4		SCREW HD UP	STEEL ZINC PL
16	4		SCREW HD UP #10-24 UNC	STEEL ZINC PL
15	5	111-0103-001	BINDING POST INSULATED	
14				
13				
12				
11				
10				
9	1	DE 2741	CIRCUIT BOARD FRONT	
8	1		CIRCUIT BOARD REAR	
7	2	DE 2242	LEVER	
6	2	DE 2240-2	PIN LOCATING	
5	1	DE 2740	SPACER	
4	1	DE 2742	LENSE	
3	1	DE 2739	LENSE HOLDER	
2	1	DE 2236	BOX MOUNTING	
1	1	DE 2235	PLATE MOUNTING	

Davis Engineering

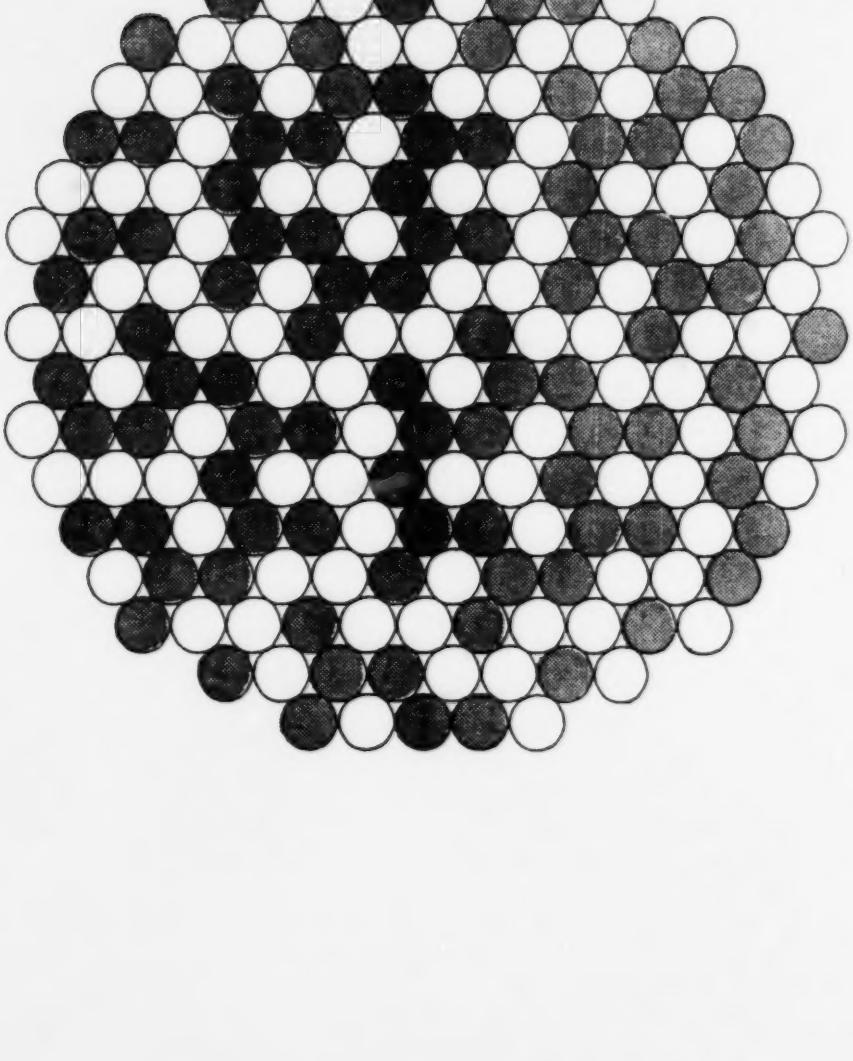
RAILROAD SIGNAL LAMP ASSY G E S Co

DE 2239

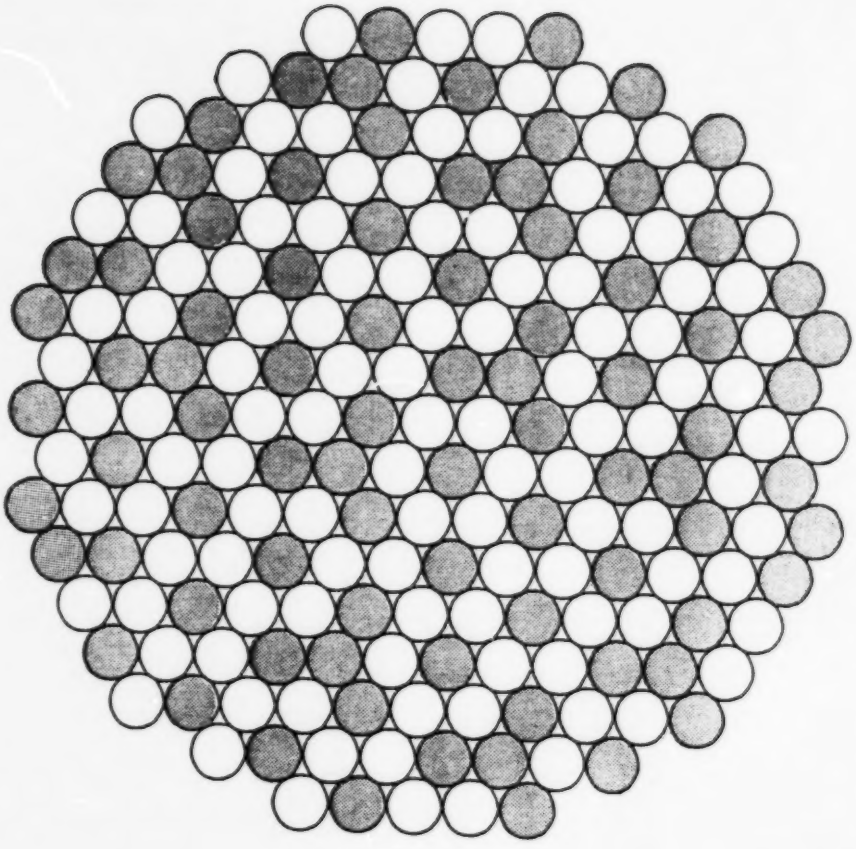
A0



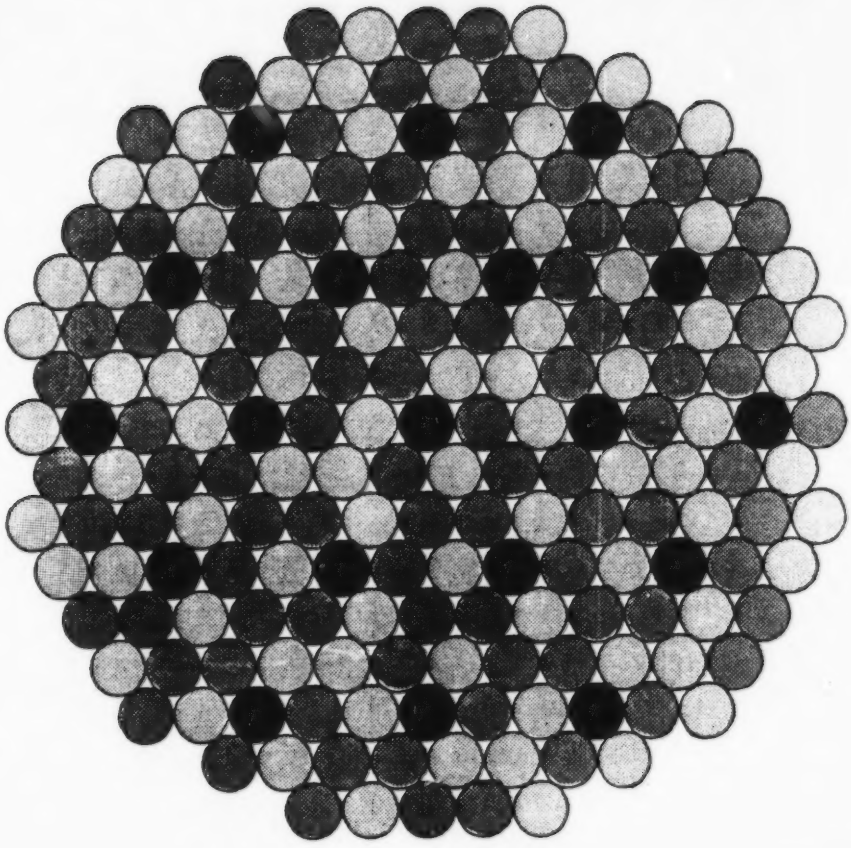
TYPE 1 ARRAY: RED ASPECT



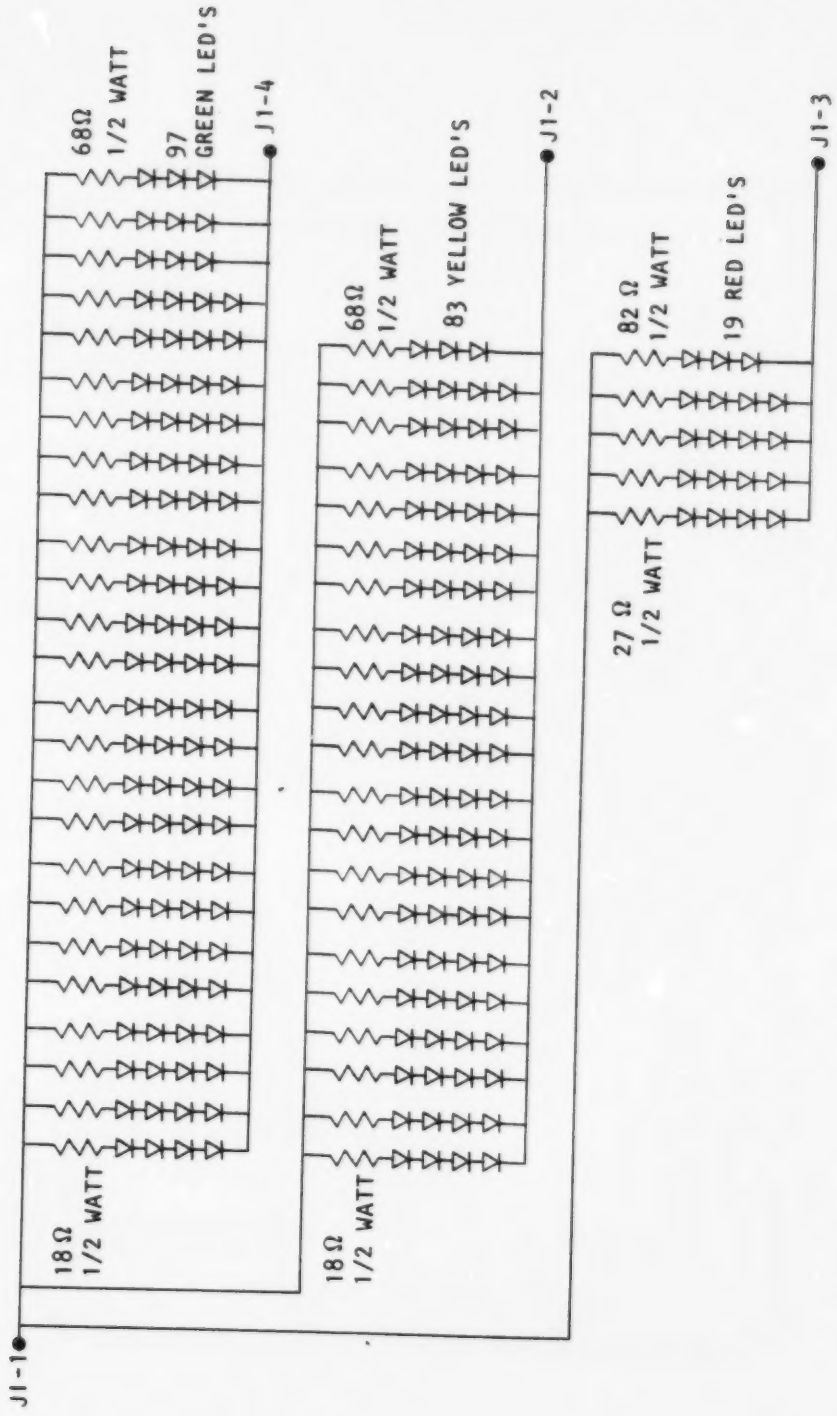
TYPE 1 ARRAY: GREEN ASPECT



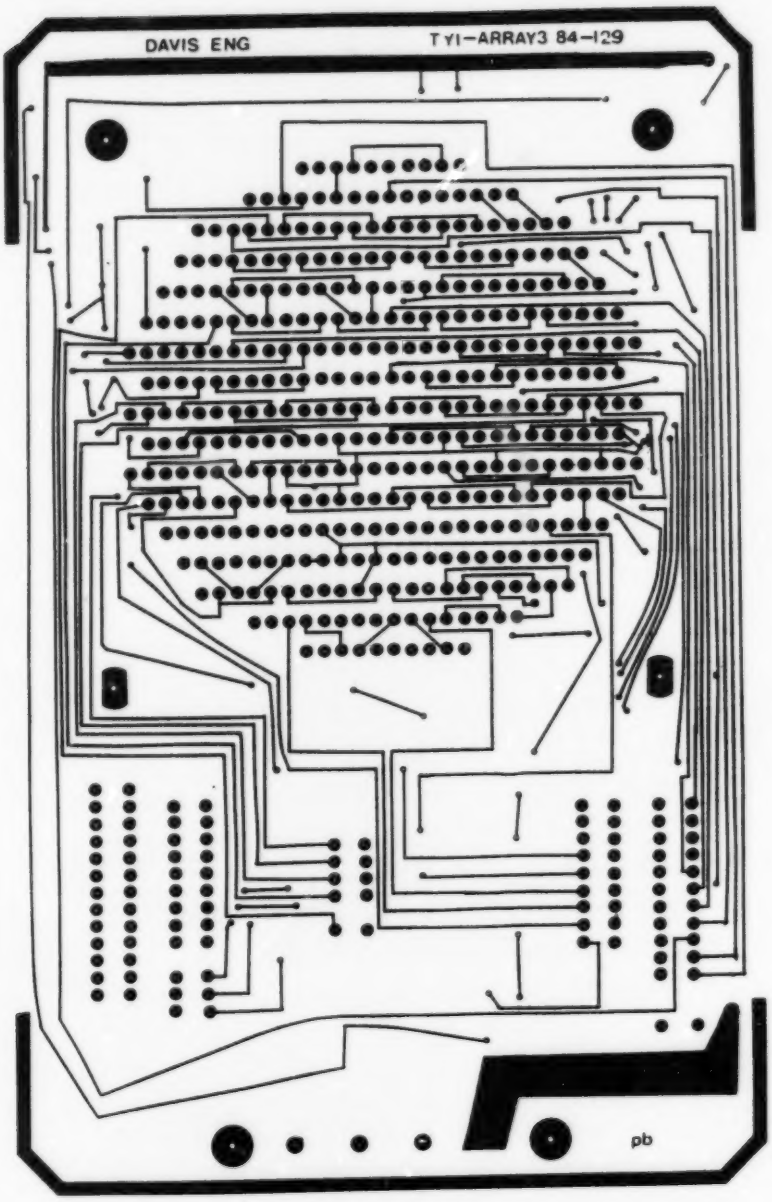
TYPE 1 ARRAY: YELLOW ASPECT



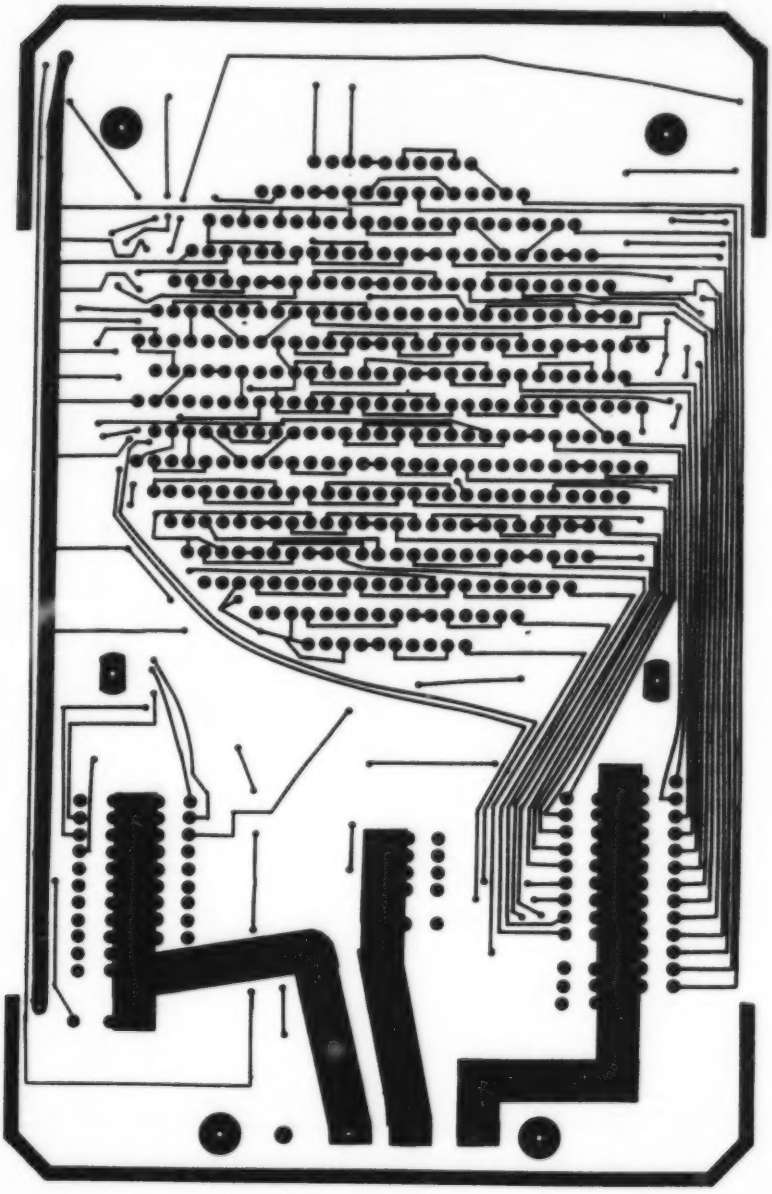
TYPE 1 ARRAY: ALL ASPECTS



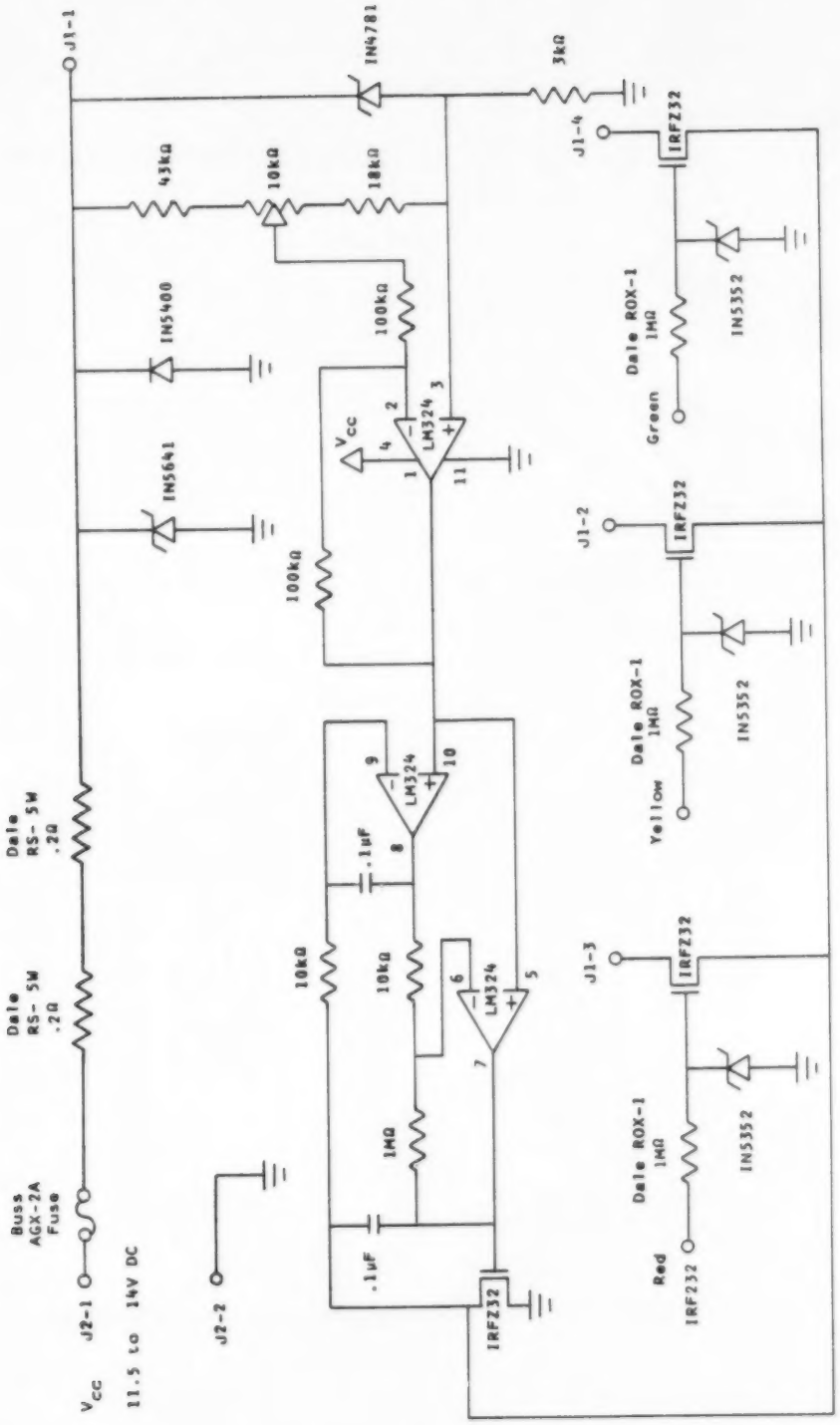
TYPE I
BOARD FRONT SCHEMATIC



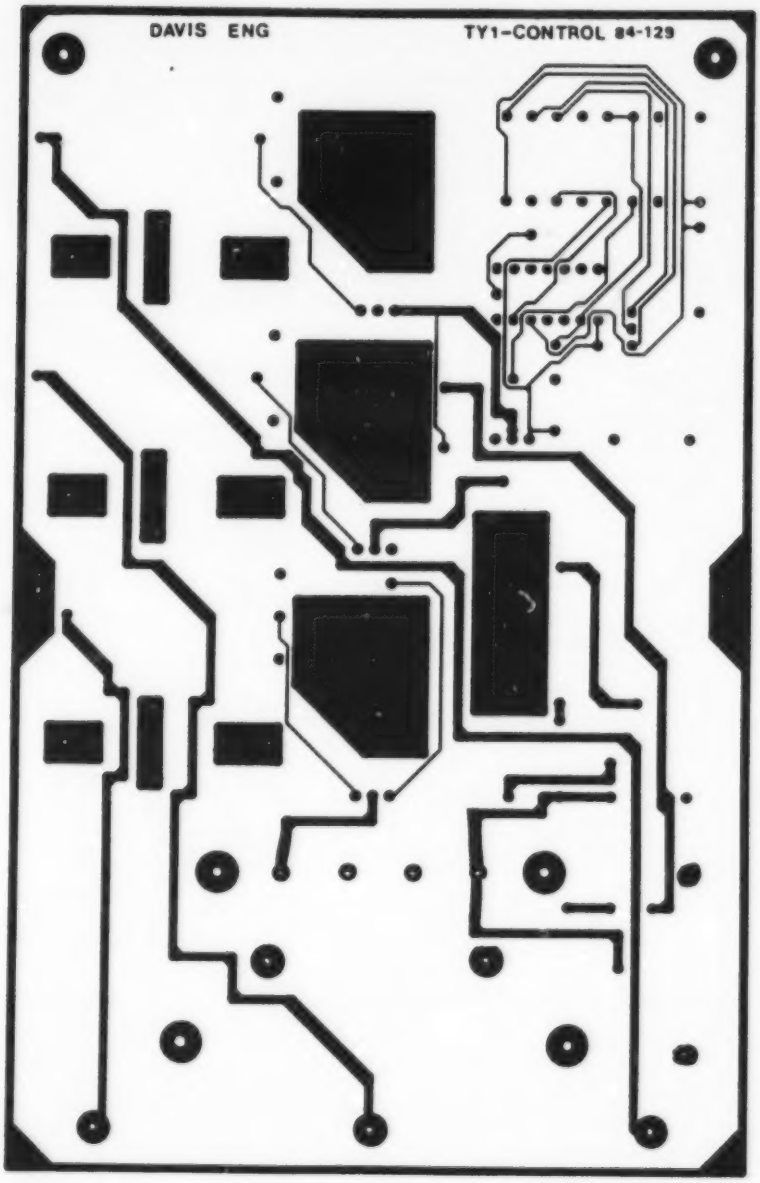
TYPE 1 BOARD FRONT-TOP LAYOUT



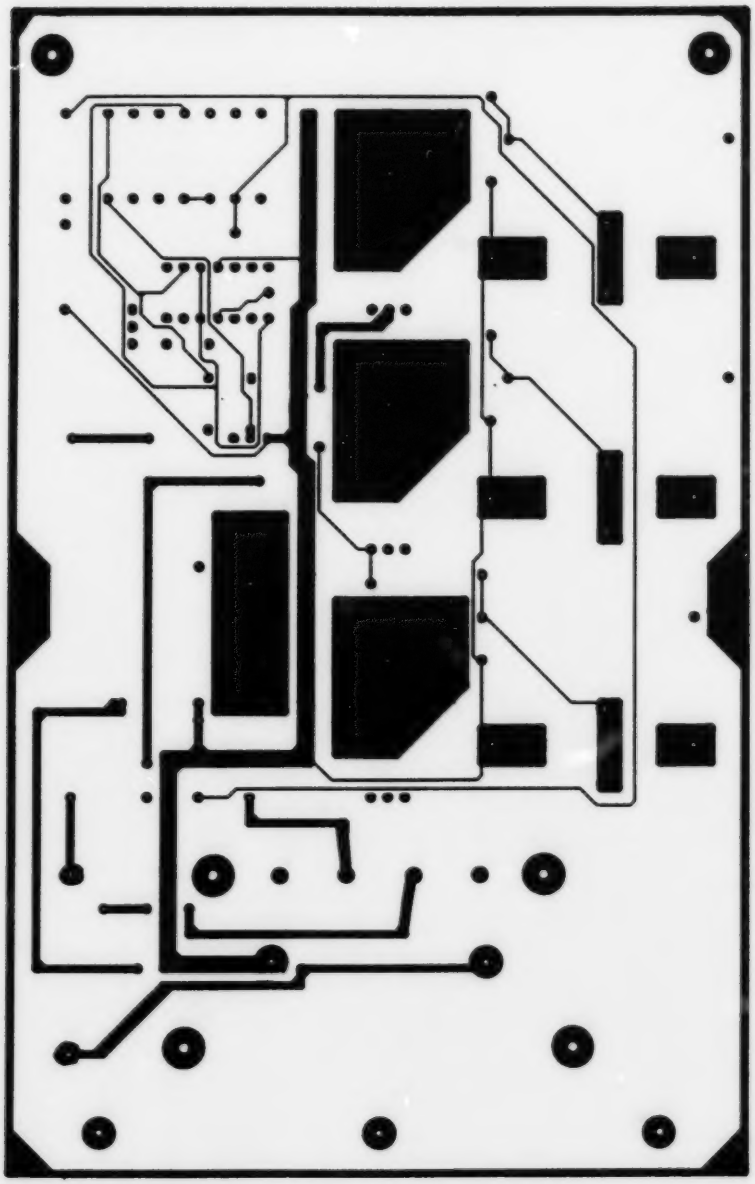
TYPE 1 BOARD FRONT-BOTTOM LAYOUT



TYPE I BOARD REAR SCHEMATIC



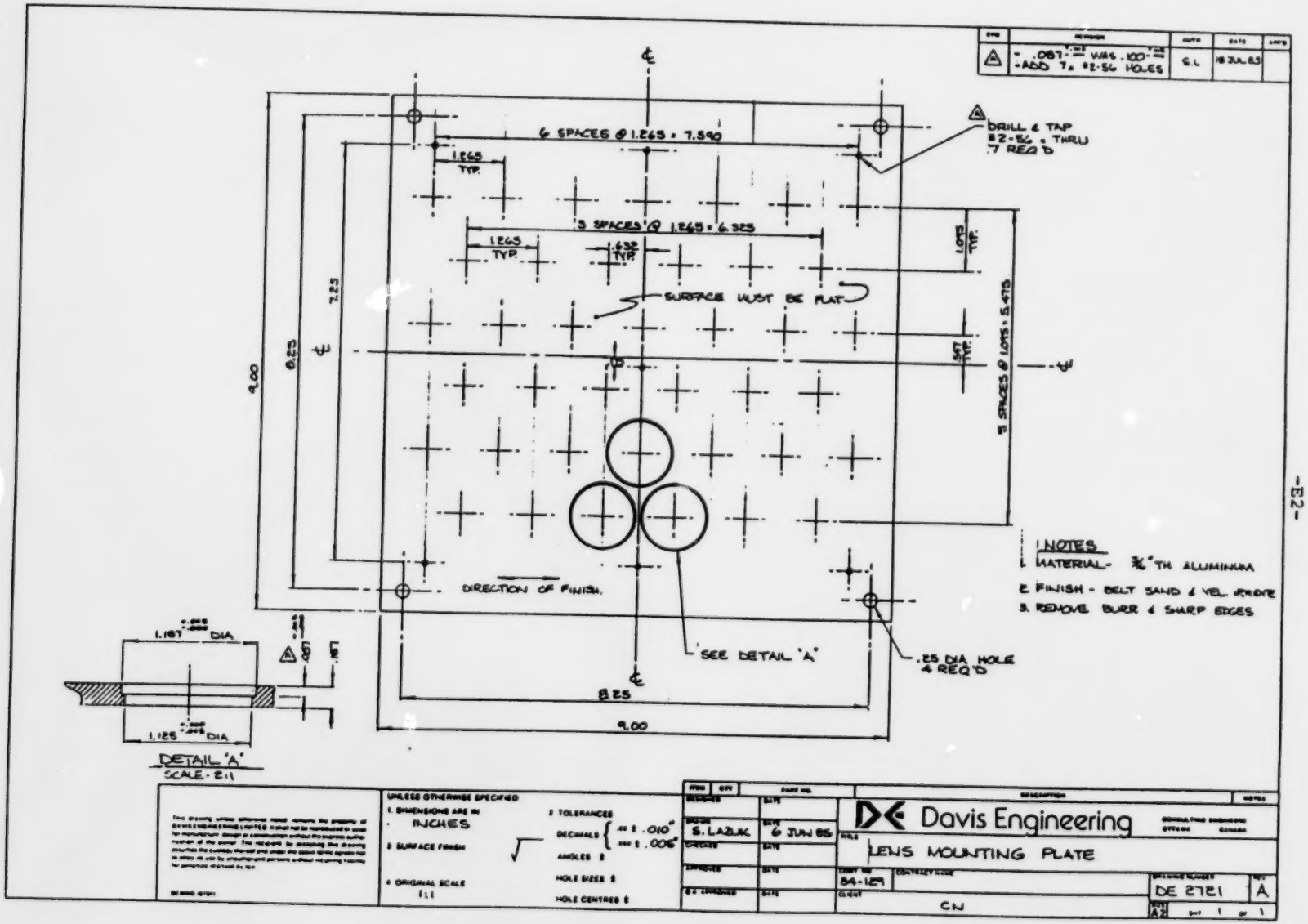
TYPE I BOARD REAR - TOP LAYOUT

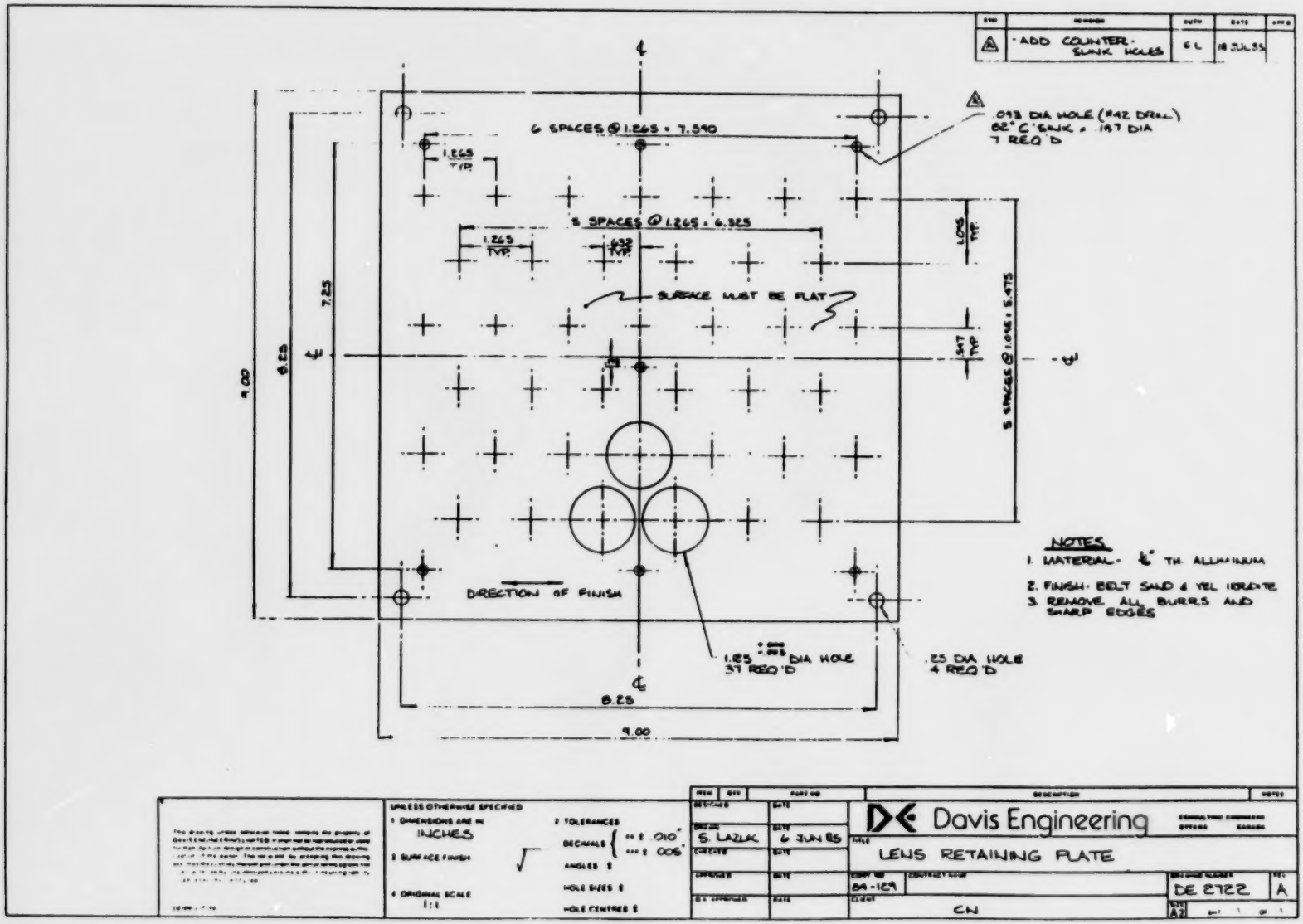


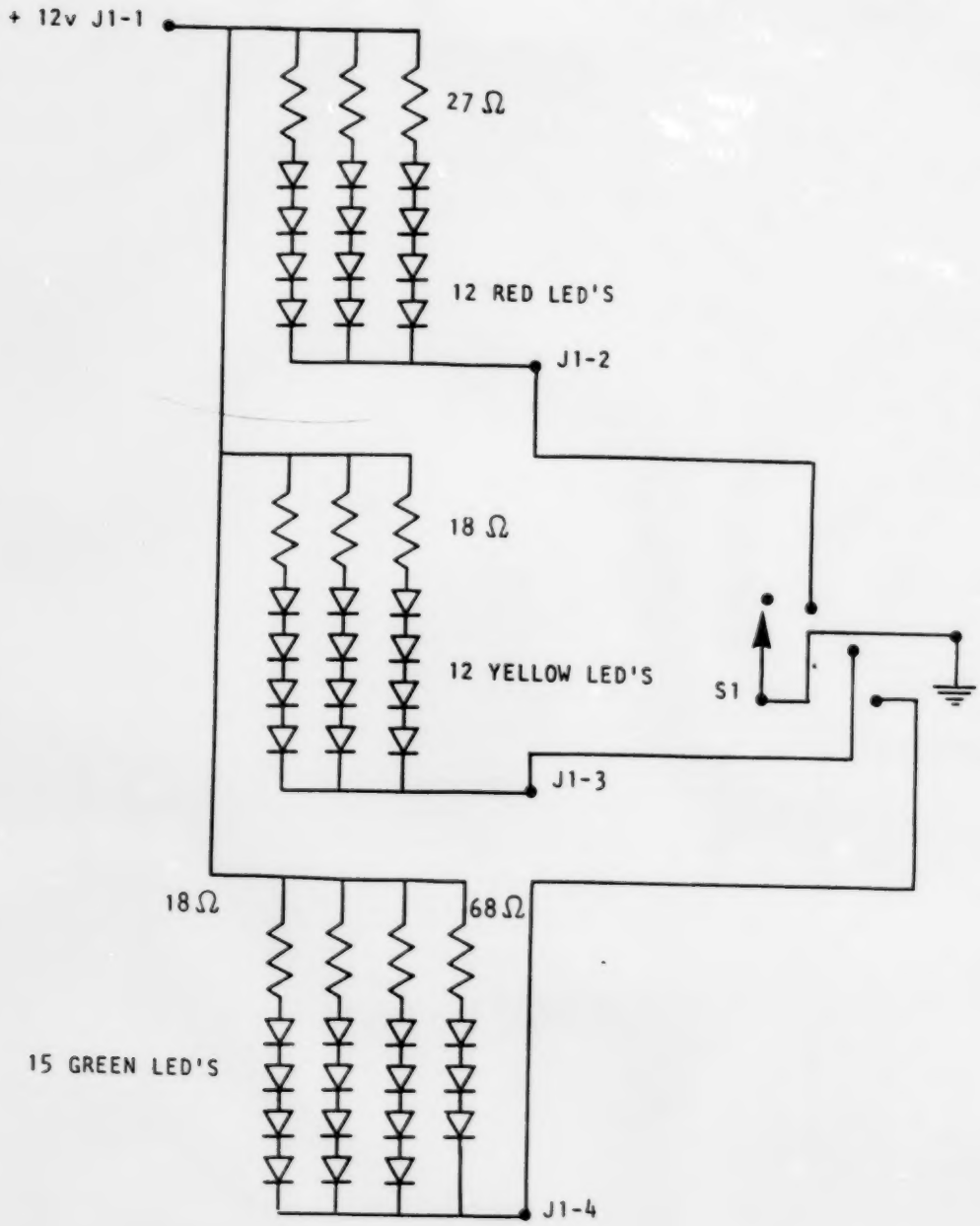
TYPE I BOARD REAR - BOTTOM LAYOUT

APPENDIX E

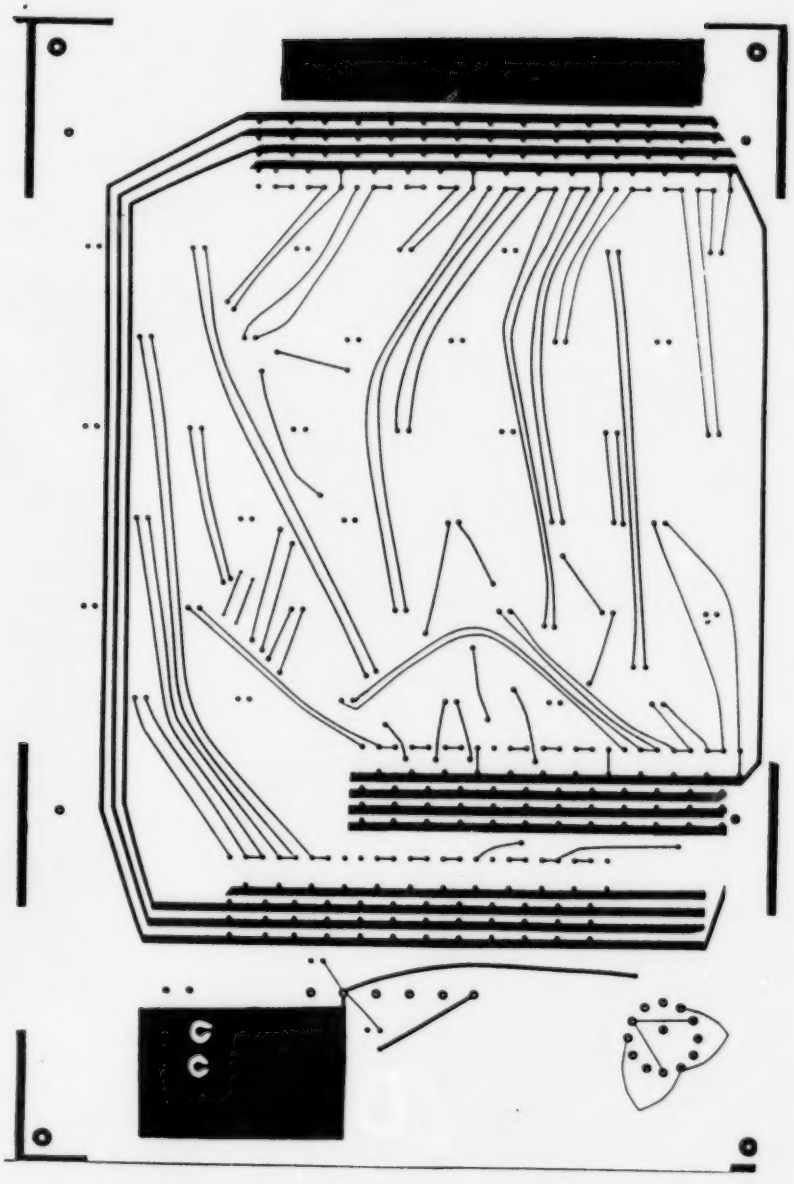
TYPE II - DRAWINGS, LAYOUTS AND SCHEMATICS


6 SPACES @ 1.265 = 7.590
1.265 TYP.
3 SPACES @ 1.265 = 6.325
1.265 TYP.
.632 TYP.
DRILL & TAP #2-56 THRU 7 REQ'D
SURFACE MUST BE FLAT
.675 TYP.
.675 TYP.
3 SPACES @ 1.675 = 5.475
9.00
8.25
7.25
DIRECTION OF FINISH
SEE DETAIL 'A'
.25 DIA HOLE 4 REQ'D
8.25
9.00
1.187 DIA
1.125 DIA
.25
.125
DETAIL 'A'
SCALE - 2:1
NOTES
1. MATERIAL - ¾"TH ALUMINUM
2. FINISH - BELT SAND & VEL. HONITE
3. REMOVE BURR & SHARP EDGES
- .087 WAS .100
- ADD 7 x #2-56 HOLES
S.L
18 JUL 83
UNLESS OTHERWISE SPECIFIED
1. DIMENSIONS ARE IN INCHES
2 SURFACE FINISH
3 TOLERANCES
DECIMALS .xx ± .010" .xxx ± .005"
ANGLES ±
HOLE SIZES ±
HOLE CENTRES ±
4 ORIGINAL SCALE 1:1
S. LADUK
6 JUN 85
Davis Engineering
LENS MOUNTING PLATE
84-129
DE 2721
A
CN
SIZE A2
SHT 1 OF 1

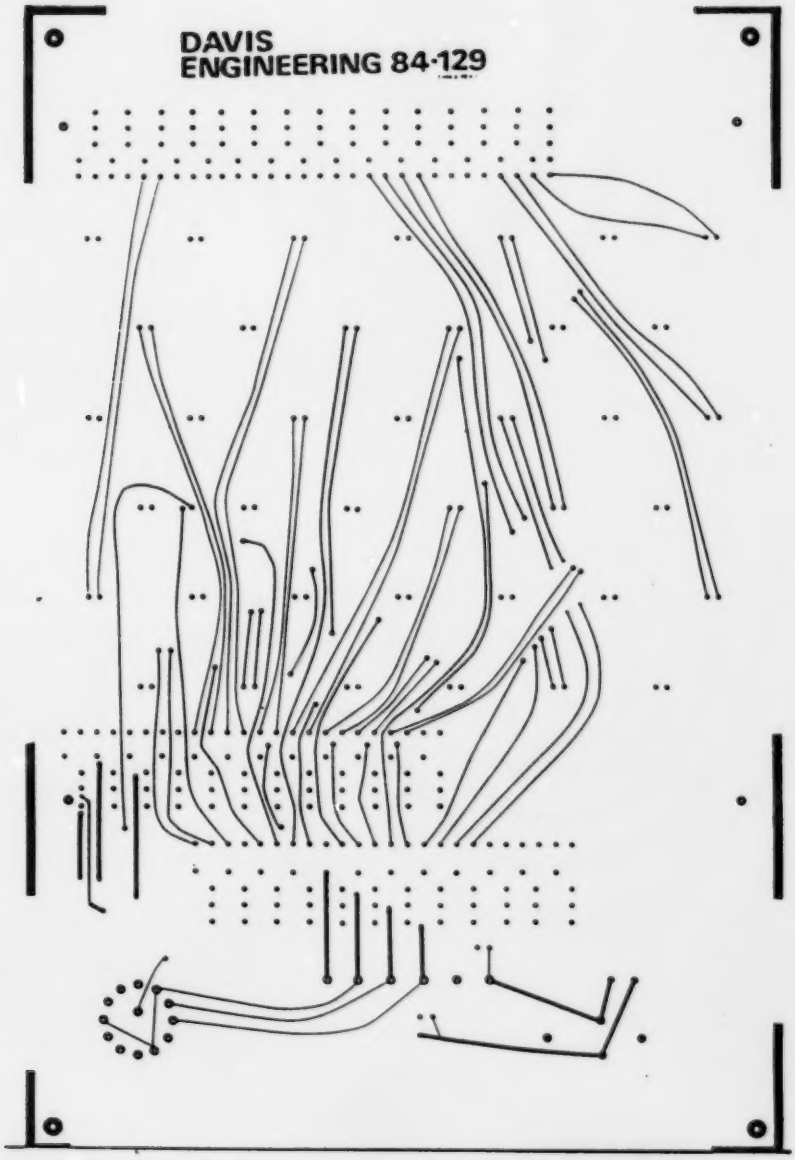

ADD COUNTER-SUNK HOLES
6 SPACES @ 1.265 = 7.590
1.265 TYP.
5 SPACES @ 1.265 = 6.325
1.265 TYP.
.432 TYP.
.093 DIA HOLE (#42 DRILL) 82° C'SINK x .197 DIA 7 REQ'D
LONG TYP.
SURFACE MUST BE FLAT
.547 TYP.
5 SPACES @ 1.094 = 5.475
7.23
8.25
9.00
DIRECTION OF FINISH
1.25 +.000 -.005 DIA HOLE 37 REQ'D
.25 DIA HOLE 4 REQ'D
8.25
9.00
NOTES
1. MATERIAL - ¼" TH. ALUMINUM
2. FINISH - BELT SAND & YEL IRIDITE
3. REMOVE ALL BURRS AND SHARP EDGES
UNLESS OTHERWISE SPECIFIED
1 DIMENSIONS ARE IN INCHES
2 TOLERANCES DECIMALS .XX ± .010" .XXX ± .005" ANGLES ± HOLE SIZES ± HOLE CENTRES ±
3 SURFACE FINISH √
4 ORIGINAL SCALE 1:1
S. LAZLK
6 JUN 85
Davis Engineering
LENS RETAINING PLATE
84-129
DE 2722
A
CN



TYPE II
BOARD SCHEMATIC



TYPE II BOARD-TOP LAYOUT



TYPE II BOARD-BOTTOM LAYOUT